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Shining a Light on Developmental Bioluminescence: From Safety Lamps to Nanobionic Green Energy

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"*The sea was luminous in specks and in the wake of the vessel, of a uniform slightly milky colour. When the water was put into a bottle, it gave out sparks…*" (Charles Darwin)

It would have been some million years ago that pre-humans discovered how to create primitive fire, and how to manufacture stone tools some million years before that (Pickrell, 2006). It would have been in Germany, Berlin, in 1938 where Otto Hahn, Lise Meitner and Fritz Strassman first discovered nuclear fusion, leading to the eventual Manhattan project and the first atomic bomb. Unsurprisingly, what should predate this? That's right, the discovery of the neutron – a subatomic particle with no positive or negative charge, a vital asset with critical applications in probing the atomic nucleus (Tretkoff, 2007). It would have been in 1832, where Charles Darwin first observed bioluminescent plankton, an event predating its eventual applications within health, elucidation and green energy.

Seeing a trend? Each discovery either acts as a signal to use the knowledge gained as a foothold for further research, a tell-tale sign of potential, or a stimulus to delve deeper and ask the renowned question – why? It is within human nature to continuously expand or enlarge our endeavours as inquirers and thinkers, appending the primordial timeline superimposed on our daily lives.

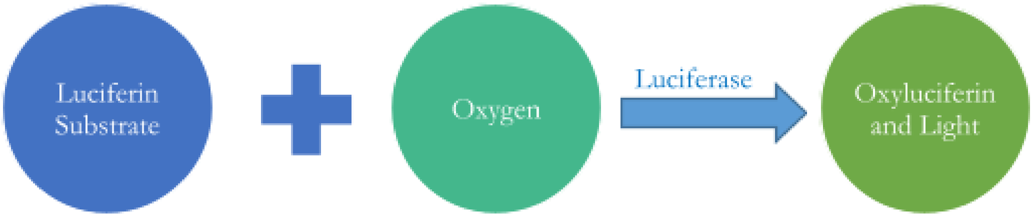
The human psyche is unique in that it is as predictable as it is dynamic. It might be tempting to say that human engagement and scientific endeavours thus far have only succeeded, or are we only perceiving a half-baked truth? As is the case with many pursuits, seeking intellectual closure is never truly enough – one must develop, exploit and investigate every crevice of a prospective field of research, such as with bioluminescence. However, what happens when we stay present in the moment and witness how even the most bewildering, incomprehensible and downright ineffectual things can have developmental potential, instead of constantly turning back time?

Observe…

The Light Within

Figure 1: Blue bioluminescence triggered by an abundance of the organism noctiluca scintillans (sea sparkle) near the Taiwanese Matsu Islands (Source: Yu-Xian Yang, AGU, 2019. Available at: https://news.agu.org/press-release/chinas-sparkling-bioluminescent-seas-are-glowing-brighter/)

Bioluminescence is a term describing the production of light energy within a living organism. It is a form of chemiluminescence, meaning it involves a chemical reaction which instigates the emission of light, namely the oxidation of a molecule known as "luciferin" (derived from Latin "Lucifer", meaning light-bearer). Additionally, quite a few organisms also produce the enzyme "luciferase", which essentially helps to speed up the reaction (Smithsonian Ocean, 2018). Luciferase acts as a catalyst, facilitating the combination of luciferin with oxygen molecules. This reaction produces photons of light which is later interpreted as luminescence, striking! (Wilson, 2021)



Alternatively, some organisms do not require enzymes to produce light. Instead, these organisms have specialised photoproteins which are capable of luminescence. Photoproteins combine with luciferin, oxygen and other ionic elements, such as calcium, to produce light proportional to their concentration/amount. (Rowe et al., 2009).

It is estimated that around 80% of deep sea marine organisms, such as algae, bacteria, jelly fish and worms, produce their own light (Davis et al., 2016); however - perhaps one of the better examples - fireflies possess this ability as well.

Figure 2: The male firefly showcasing quick, bright flashes to lure and court females (Source: Alex Wild, TED, 2016. Available at: https://ideas.ted.com/how-fireflies-are-beautiful-and-useful/)

Surprisingly, some bioluminescent organisms which are incapable of synthesizing luciferin are able to absorb it through their diet or through forming symbiotic relationships. Such is the case with some types of squid, which form symbiotic bonds with light capable bacteria inhabiting their light organs. Other species of fish, such as midshipman fish, obtain luciferin through the ingestion of seed shrimp (National Geographic, n.d.)

Not Just a "Pretty Light"

Contrary to popular predisposition, bioluminescence is not just a "pretty light", in fact its evolutionary development and associated survival mechanisms merit a substantial amount of investigation.

Illumination is vital in hunting prey, defending against predators, finding mates and executing other important activities. For example, take the vampire squid which, being a deep-sea creature and lacking ink sacs, ejects a sticky luminescent mucus to startle and delay its predators (National Geographic, n.d.).

Throughout biological history, bioluminescence has been shown to evolve 27 separate times (Newitz, 2016). Deep sea environments are quite dark and therefore conducive to a contrast in light from bioluminescence, thereby amplifying the evolutionary benefits of the trait. However, it is theorised that terrestrial bioluminescence, such as in the case of fireflies, evolved much later due to the prevalence of light pollution on land (Gruber, 2012).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Firefly

- Firefly bioluminescence is believed to have originated as a means to ward off potential predators.
- They have also evolved bioluminescence as unique visual cues for courtship. Most fireflies are only found in moist environments such as forests, lakes or mangroves (Wu, 2018).

Anglerfish

- The species specific glow of the anglerfish is critical for luring potential mates. The female uses the lure to attract males which haplessly attach onto the female and fertilise her eggs (Spencer, 2019).
- Female anglerfish also utilise their lure to entice fish and other crustaceans.

Bobtail Squid

- Bobtail squid possess a characteristic symbiotic relationship with the bacteria known as *vibrio fischeri*. The squid provides the bacteria with food and uses the resulting blue light for camouflage in moonlit waters (Spencer, 2019).

Throughout history, tribes and ancient groups have long been exploiting the properties of bioluminescence. In fact, some Scandinavian tribes have been known to use pieces of wood which glows due to bioluminescence when venturing deep into forest landscapes (BBC Travel, 2015).

During the moist and humid monsoon season in the Western Ghats of India, the conditions are ripe for the growth of certain bioluminescent fungi from the Mycena genus. The rain-drenched forests can give off an enchanting green glow, emanating in the pitch black environment powerfully, yet overlooked just the same. Traveller Neelima Vallangi, who was hiking through the jungles of Maharashtra in India, says that "when we switched off our torches to wait for the rest of the group, a faint green glow emanated from the ground around us. Astounded, our eyes adjusted to the dark." (Vallangi, 2015). This experience implies how overlooked certain phenomena are, harbinger signalling that there is more to be found that meets the eye.

In addition to its historical development, the chemical properties of bioluminescence has proved invaluable in terms of its more practical applications within the fields of public health, research and medical knowledge.

Contaminated food, that is food unsafe for consumption, is detected through a type of analysis called bioluminescent ATP assay. ATP (adenosine triphosphate) is the primary source of energy for all living cells and microbes and can be detected through adding firefly luciferase and luciferin. When these compounds are added, the ATP present in the microbial contaminants produces visible light. The resultant intensity of light being emitted can be used to ascertain the amount of bacteria present in foods such as milk, soft drinks and meat (Lewis, 2016).

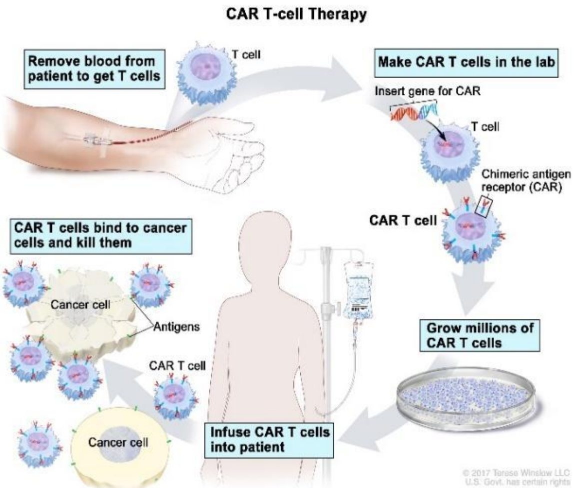

Figure 3: CAR T-cell therapy, in which T immune cells are lab modified to help fight cancer (Source: National Cancer Institute, 2019. Available at: https://www.cancer.gov/publications/dictionaries/cancer-terms/def/car-t-cell-therapy)

Additionally, bioluminescence has led to improved ways of developing critical immunotherapies, stated as "One of the most promising areas in cancer research" by chief of haematology at the USC department of Medicine, Preet Chaudary (Dybas, 2019). A common example of cancer immunotherapy is CAR-T cell therapy, in which a person's immune T cells are changed in the lab to bind to cancerous cells and kill them (National Cancer Institute, 2019).

Chaudary also states how his colleagues have developed a more precise assay: the Matador Assay. Based on the chemical luciferase, this bioluminescent assay involves the introduction of the luciferase enzyme into cancerous cells. The enzyme leaks out when the cells die, leaving a glow. This it an invaluable monitoring tool for accurately recognising the death of a single cancer cell. Matador's effectiveness has been tested in several cancers, including myelogenous leukaemia, acute myelogenous leukaemia and Burkitt lymphoma (Dybas, 2019). "The Matador assay can detect cell death in 30 minutes", says Chaudary, allowing for a more effective and targeted CAR-T cell immunotherapy treatment. Another type of luciferin assay, known as the Topanga assay, is being used to monitor the expansion and growth of CAR-T cells post-administration in order to ascertain toxic reaction risks, and those who are at risk of cancer relapse due to short-lived immune cell action (Masatani, 2019).

Light Switching

From abyssal depths to your study desk, recent developments in bioluminescence have led to the creation of nanobionic plants which might one day replace conventional electrical lighting. “The light is ultimately powered by the energy metabolism of the plant itself,” says Michael Strano, professor of chemical engineer and the senior author of the research (Trafton, 2017). Essentially, the nanobionic plant involves three primary components, luciferin, luciferase and another molecule called co-enzyme A, which helps by removing an inhibitory reaction by-product.

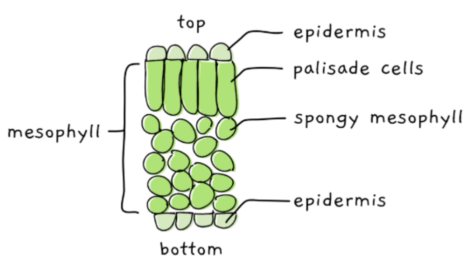

Figure 5: Plant mesophyll diagram (Source: Joram, Plants and Pipettes, 2019. Available at: https://plantsandpipettes.com/the-grass-is-greenest-on-the-inside/)

ıre 4: Nanobionic induced bioluminescence from a rcress plant (Source: Anne Trafton, MIT, 2017. lable at: ://news.mit.edu/2017/engineers-create-nanobionic-plthat-glow-1213)

The researchers used nanoparticle carriers about 10 nanometres in diameter made specifically to occupy certain parts of the plant’s internal leaf tissue, also known as *mesophyll*. For instance, the poly[lactic-co-glycolic acid] (PLGA for short) particles designated with releasing luciferin and co-enzyme were designed to collect in the *extracellular* layer of the mesophyll, while the silicon luciferase nanoparticles collected in the cells of the mesophyll. This creates an interesting biological interplay, in that the PLGA particles gradually release luciferin, which then enters the plant cells and subsequently undergoes the chemical reaction which produces light.

Luminous Ultimatum

Conclusively, it can be noted how the aforementioned applications of bioluminescent can instigate a discussion around what is to be derived from evolution’s naturally innovative processes and development. All the more reason to be inspired by and celebrate evolution’s beauty, inventiveness and endless possibilities!

Since light is omnipresent and, arguably, the most important tool in any form of analysis or scientific elucidation technique, perhaps bioluminescent is the developmental key moving forwards? What happens if we continue to develop it, use it in biological assays, nanobionic plants and studies of microbial contaminants?

Moving forwards, however, future urban light pollution may lead to a sharp decline in the potency and pervasiveness of the bioluminescent trait, meaning less and less people will get to enjoy its striking brilliance. But for now, let’s just sit by the bioluminescent campfire, enjoying our company abreast, and watch as the inviting light pulsates and glows with anticipation. So, how long before the reaction sparking in front of us begins burning within?

Word Count: 1675

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