生物策略表

類別	生物策略 (Strategy)
生物策略 STRATEGY	常見東方螢火蟲（*Photinus pyralis*）通過一種迷人的生物化學過程稱為生物發光來產生光 What Lights a Firefly’s Fire? Common eastern firefly
生物系統 LIVING SYSTEM	*Photinus pyralis* 東方螢火蟲
功能類別 FUNCTIONS	#Send Light Signals in the Visible Spectrum #傳遞光訊號
作用機制標題	常見東方螢火蟲通過一種化學反應產生光，這個反應使分子獲得能量，從而釋放出光子。The common eastern firefly produces light through a chemical reaction that energizes a molecule so it can release a photon.
生物系統/作用機制示意圖 (確認版權、註明出處；畫質)	  Gail Shumway/Photographer's Choice/Getty Images
作用機制摘要說明 (SUMMARY OF FUNCTIONING MECHANISMS)	

生存策略:

很少有自然現象能與夏夜高草叢中螢火蟲閃爍的奇幻景象相媲美。當夜幕降臨在美國東部和中部的草地與森林邊緣時，*Photinus pyralis* 種類的雄性螢火蟲在空中飛舞，腹部的生物發光燈忽明忽滅，地面上的雌性螢火蟲則閃爍著光芒作為回應，吸引雄性前來進行繁殖相會。

螢火蟲閃光的功能早已為人所知，而更近期的研究則揭示了其發光機制的詳細運作方式，科學家發現，這一特性可追溯至螢火蟲發光器官內部的發光細胞中的五種關鍵分子：螢光素、螢光素酶、腺苷三磷酸、一氧化氮和氧氣。

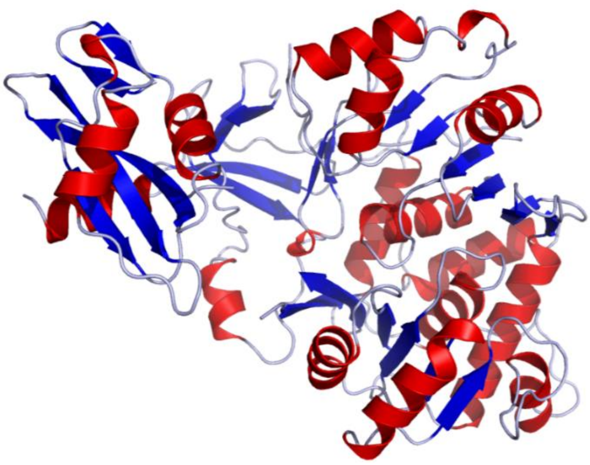
昆蟲不像人類那樣擁有肺，而是透過稱為氣管的細管將氧氣輸送到體內，氧氣沿著氣管進入發光細胞，並與粒線體結合，通常粒線體會利用氧氣來釋放能量，以維持細胞的正常運作，當螢火蟲準備發光時，它們會釋放一氧化氮，使其與粒線體結合，從而釋放出氧氣，供給即將展開的發光反應，氧氣隨後進入另一種細胞結構——過氧化體，真正的發光反應便在此處開始。

在過氧化體內，生物發光反應透過螢光素酶進行，這種酶擁有特殊的結構，內部設有「結合位點」，專門用來固定熒光素和腺苷三磷酸。當熒光素與腺苷三磷酸嵌入結合位點後，兩者便能夠靠近並結合，形成螢光素-ATP 複合物，接著，一個游離的氧分子與該複合物結合，形成氧化螢光素，這是一種處於「激發態」的分子，迫不及待地釋放能量，當它釋放能量時，會以光子的形式發出，也就是螢火蟲特有的黃綠色閃光，隨後另一種酶，螢光素再生酶會將氧化熒光素轉回為螢光素，讓螢火蟲準備好再次閃耀光芒。

策略:

由於螢火蟲能夠在不產生多餘熱量的情況下發光，模仿其發光機制或許能夠促進更節能的人工光源開發，此外螢火蟲利用單一分子（在此指氧氣）作為開關來啟動發光反應的機制，也啟發了在極短時間內交替控制光與暗的新方法——這種效應可能對顯示螢幕及其他電子設備的發展有所幫助。

由於螢火蟲的發光需要 ATP，而 ATP 廣泛存在於微生物體內，螢光素-螢光素酶系統已被應用於檢測飲料（如豆漿和茶）中的細菌含量。



圖一、螢光酶的結構，可用來將另外兩種分子結合在一起，形成一種複合物，當與氧結合時，就能產生光亮。

The Strategy

Few natural phenomena can match the magic of fireflies flashing in the tall grass on a summer's night. As dusk falls on grassy meadows and forest edges of the eastern and central United States, males of the species *Photinus pyralis* flit about, flicking on and off bioluminescent lanterns in their abdomens. On the ground, females flash in response, attracting the males for a reproductive rendezvous. The romantic function of the flash has long been known. What's more recently been uncovered is a clear understanding of exactly how it happens. Scientists have tracked the trait down to a set of five molecules located in light-producing cells called photocytes that line a firefly's lantern: luciferin, luciferase, adenosine triphosphate (ATP), nitric oxide (NO), and oxygen. Insects do not have lungs like humans do, but instead transport oxygen into their bodies through tubes called tracheoles. Oxygen travels through the tracheoles and enters the photocytes, where it binds to mitochondria. Normally the mitochondria would use the oxygen to release energy for regular cellular processes. But when it's time to glow, fireflies send nitric oxide to bind to the mitochondria instead, freeing up the oxygen to fuel the light show about to begin. The oxygen enters another cellular structure, the peroxisome, and that's where the fun begins. Inside the peroxisome, bioluminescent reactions occur using luciferase, an enzyme with customized cubbyholes (called "binding sites") for luciferin and ATP. The luciferin and ATP tuck themselves into the binding sites, which bring the two molecules close enough to each other that they can combine to form a luciferin-ATP complex. A molecule of the freed-up oxygen then combines with the complex to form oxyluciferin, an "excited" molecule that's eager to release a burst of energy. When it does, it releases it in the form of a photon—a packet of light—creating the characteristic yellow-green glow. Another enzyme, luciferin-regenerating enzyme, then turns the oxyluciferin back into luciferin, ready to make another flash. **The Potential** Because fireflies produce light without excess heat, mimicking their methods may help pave the way to developing more energy-efficient artificial light sources. And the mechanism of using the presence of a single molecule (in this case, oxygen) as an on-switch can inspire new ways to alternate between light and darkness over extremely short time periods—an effect that could be useful in display screens and other electronics. Additionally, because it needs ATP to glow and ATP is found in microorganisms, the luciferin-luciferase combination has been used to detect the presence of germs in beverages such as soy milk and tea.
文獻引用 (REFERENCES)

In a firefly bioluminescence reaction, an enzyme known as a luciferase uses adenosine triphosphate (ATP) to activate a molecule called a luciferin. The product of this reaction combines with molecular oxygen to produce an excited-state oxyluciferin species. When oxyluciferin relaxes back to its ground state, energy is released in the form of light. There are variations on this theme, of course. One of the fascinating aspects of bioluminescence is how many variations have evolved. Different organisms have come up with structurally different luciferins and enzymes to attain bioluminescence. (Pepling 2006:36)

Journal article**All That Glows: Bioluminescence provides practical applications while still remaining a mystery**

Chemical & Engineering News | 2006 | R.S. Pepling

在螢火蟲生物發光反應中，螢光素酶利用 ATP 活化螢光素，然後與分子氧結合，形成激發態的氧化螢光素，當氧化螢光素回到基態時，會釋放光能。生物發光的一個迷人之處是它已經進化出如此多的變化，不同生物體產生了結構不同的螢光素和酵素來實現生物發光。

Firefly luciferase produces light by converting substrate beetle luciferin into the corresponding adenylate that it subsequently oxidizes to oxyluciferin, the emitter of bioluminescence. We have confi rmed the generally held notions that the oxidation step is initiated by formation of a carbanion intermediate and that a hydroperoxide (anion) is involved. Additionally, structural evidence is presented that accounts for the delivery of oxygen to the substrate reaction site. Herein, we report key convincing spectroscopic evidence of the participation of superoxide anion in a related chemical model reaction that supports a single electron-transfer pathway for the critical oxidative process. (Branchini et al. 2015:7592)

Journal article

Experimental Support for a Single Electron-Transfer Oxidation Mechanism in Firefly Bioluminescence

J. American Chemical Society | June 9, 2015 | B.R. Branchini, C.E. Behney, T.L. Southworth, D.M. Fontaine, A.M. Gulick, D. J. Vinyard, G.W. Brudvig

螢火蟲螢光素酶透過將甲蟲螢光素轉化為相應的腺苷酸，隨後將其氧化為氧化螢光素（生物發光的發射源）來產生光。氧化步驟是由碳負離子中間體的形成引發的，並且涉及氫過氧化物，此外也提供了解釋氧氣輸送到底物反應位點的結構證據。在此，我們報告了超氧化物陰離子參與相關化學模型反應的關鍵令人信服的光譜證據，該證據支持關鍵氧化過程的單一電子轉移途徑。

Journal article

Biologically inspired LED lens from cuticular nanostructures of firefly lantern

Proceedings of the National Academy of Sciences | 30/10/2012 | J.-J. Kim, Y. Lee, H. G. Kim, K.-J. Choi, H.-S. Kweon, S. Park, K.-H. Jeong

受螢火蟲發光構造的表皮奈米結構啟發的生物 LED 透鏡

參考文獻清單與連結 (REFERENCE LIST) **Harvard 或 APA 格式**

https://asknature.org/strategy/light-generated-chemically/#references

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補充影片:
Firefly Experience - Summer Night with Fireflies (Lightning Bugs)
https://www.youtube.com/watch?v=k72jGJTC_3o