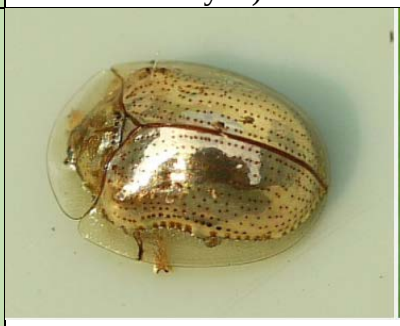
生物策略表

類別	生物策略 (Strategy)
生物策略 STRATEGY	反射結構造成顏色及表面改變 (Reflector causes color and surface change)
生物系統 LIVING SYSTEM	金花蟲 Cassidinae (Tortoise beetle)
功能類別 FUNCTIONS	#從環境中感應光訊號（可見光譜） #感應大氣條件訊號 #Sense light (visible spectrum) from the environment #Sensing atmospheric conditions
作用機制標題	金花蟲的外骨骼由於其充滿溝紋的啁啾式多層反射構造，能分別以填充或抽空液體，造成遮蔽或顯露最底層色澤，從而改變顏色及反射特性 (The exoskeleton of the tortoise beetle changes color and reflective properties due to a chirped multilayer reflector filled with grooves that fill and empty of fluid to cover and reveal, respectively, the bottommost layer.)
生物系統/作用機制示意圖	 

作用機制摘要說明 (SUMMARY OF FUNCTIONING MECHANISMS)

當看到金花蟲時，有人可能會以為看到的是在葉片表面的一滴露水，因為其金屬色的光澤帶有反射光芒。然而當移開目光後，有人可能會覺得這隻昆蟲消失了，然後被替代成一隻紅瓢蟲。不要被欺騙了，這其實就是之前的那隻甲蟲！在甲蟲堅硬而透明的盔甲下，是有著複雜精細的多層結構，充滿了具有樣式的溝紋。這些層次隨著位於越底層而變得越厚（一種被稱為啁啾式多層 chirped multilayer 的構造）。

濕氣使這些溝紋充滿濕度。當這種甲蟲受到幾乎任意形式的騷擾時，都會使溝紋中的液體轉移到多層構造的最表面部分，因此展露出最底層中深色而反射度較小的紅色色澤。這一層呈現出廣角漫射 (wide-angle diffusion) ，故缺乏金屬光澤而不會展現金色。這種類型的形態可以用「調光鏡理論」(switchable mirror theory) 解釋，其中大小不一的多孔層提供了散亂的空間樣式可進行濕氣轉移。這與很多以液壓機制 (hydraulic mechanism) 來解釋當液體注入一個區域（或是相反地從一個區域中移出）時使顏色變化的著名理論相衝突。金花蟲令人印象深刻的是牠可以在這兩種非常不一樣的顏色及明暗之間切換。完整的機制雖然尚未完全瞭解，但肯定的是如果這可以被瞭解，在紡織及感測領域的發展能獲益良多。

When gazing upon the golden tortoise beetle one may think they are observing a dew drop on the surface of a leaf, for its metallic sheen gives off a reflective glare. One glance away, however, and one may think the beetle has disappeared to be replaced by a red lady beetle. Not to be fooled, this insect is the same one as before! Under the hard, transparent armor of the beetle is an intricate multilayer filled with a pattern of grooves. The layers become thicker farther down the layered column (a structure referred to as a "chirped" multilayer).

Moisture causes humidity to fill these grooves. When the beetle is disturbed, in virtually any manner, the fluid in these grooves is displaced in the top-most parts of the multilayer thus revealing a deep, less-reflective red-color in the bottommost layer. This layer manifests a wide-angle diffusion, lacking the metallic properties that the gold coloring displayed. This type of morphism is explained using the "switchable mirror theory" where random porous patches provide a scattered pattern of space in which moisture may be displaced. This contradicts many well known theories where a "hydraulic mechanism" is used to explain color change when liquid is injected into an area (as opposed to displaced out of an area). The remarkable thing about the golden tortoise beetle is that it is able to toggle between these two very different colors and shading. The full mechanism is not entirely understood, but it is certain that if it could be understood, applications in the textile and sensory areas of development could benefit greatly.

文獻引用 (REFERENCES)

一種金花蟲 (*Charidotella egregia*) 在受到外在壓力事件騷擾時能夠可逆地改變其表皮的結構色。在進行野外觀察、測量兩個穩定顏色狀態的光學特性，以及使用掃描式電子顯微鏡及穿透式電子顯微鏡調查後，一個解釋這種昆蟲的顏色切換現象的物理機制被提出。這種動物在休息狀態下呈現的金黃色澤，被證實是由濕氣存在於每一層的多孔層中，使啁啾多層反射構造維持在完美同調狀態下所產生；而在受到騷擾後展示出的紅色色澤，則是由於從多孔層中排除液體而造成這個反射構造被破壞的結果，原本多層反射結構轉換成透明的平板，使深層的紅色色素基質沒被阻擋而變得可見。這個機制不只解釋了色調的轉換，亦解釋了從鏡面到漫射的散射模式變化…我們可以把這種行為稱為「濕氣染色」(hygro-chrome)，以強調顏色會隨濕度而變化。可調控材料 (Tunable materials) 例如會因應施加電場而改變顏色的電致變色薄膜 (electrochome films) 或因應溫度而改變顏色的熱致變色薄膜 (thermo-chrome films) ，皆有強大應用潛力於感測或切換裝置上。」(Vigneron et al. 2007: 1, 10)

"The tortoise beetle *Charidotella egregia* is able to modify the structural color of its cuticle reversibly, when disturbed by stressful external events. After field observations, measurements of the optical properties in the two main stable color states and scanning electron microscope and transmission electron microscope investigations, a physical mechanism is proposed to explain the color switching of this insect. It is shown that the gold coloration displayed by animals at rest arises from a chirped multilayer reflector maintained in a perfect coherent state by the presence of humidity in the porous patches within each layer, while the red color

displayed by disturbed animals results from the destruction of this reflector by the expulsion of the liquid from the porous patches, turning the multilayer into a translucent slab that leaves an unobstructed view of the deeper-lying, pigmented red substrate. This mechanism not only explains the change of hue but also the change of scattering mode from specular to diffuse…We can refer to this behavior as 'hygro-chrome', underlining the change of color with varying hygrometry. Tunable materials like electrochrome films change color with varying applied electric fields or thermo-chrome films that change color with varying temperatures all have a strong potential for applications in sensing or switching devices". (Vigneron et al. 2007: 1, 10)

參考文獻清單與連結 (REFERENCE LIST)

Vigneron, J. P., J. M. Pasteels, D. M. Windsor, Z. Vértesy, M. Rassart, T. Seldrum, J. Dumont, O. Deparis, V. Lousse, L. P. Biró, D. Ertz, and V. Welch. (2007). Switchable reflector in the Panamanian tortoise beetle *Charidotella egregia* (Chrysomelidae: Cassidinae). *Phys. Rev. E* 76: 031907. (https://doi.org/10.1103/PhysRevE.76.031907)

延伸閱讀

生物系統延伸資訊連結 (LEARN MORE ABOUT THE LIVING SYSTEM/S)

https://en.wikipedia.org/wiki/charidotella_sexpunctata
https://www.onezoom.org/life/@charidotella_sexpunctata
https://eol.org/pages/970665

撰寫/翻譯/編修者與日期

譚國鎏翻譯 (2021/03/22)；阮文滔編修 (2021/04/07)

AskNature 原文連結

https://asknature.org/strategy/reflector-causes-color-and-surface-change/