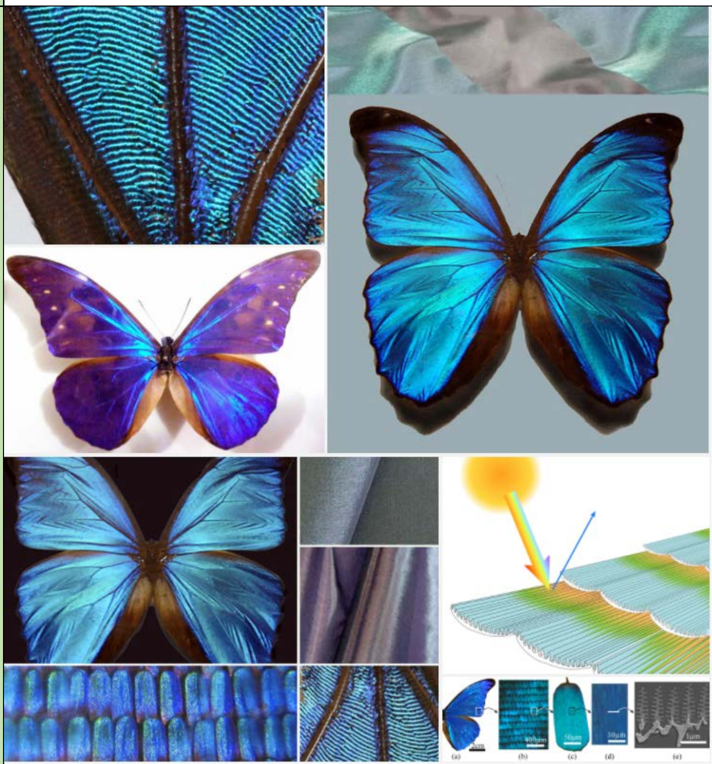
生物策略表

類別	生物策略 (Strategy)
生物策略 STRATEGY	翅膀鱗片使光線折射及干涉 (Wing scales cause light to diffract and interfere)
生物系統 LIVING SYSTEM	閃蝶屬 *Morpho*
功能類別 FUNCTIONS	#改變光線/顏色 #Modify light/color
作用機制標題	藍閃蝶翅膀透過使光波繞射及干涉產生色彩 (Wings of Morpho butterflies create color by causing light waves to diffract and interfere.)
生物系統/作用機制示意圖	

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

多種蝴蝶利用翅膀鱗片上能與光線互相作用的結構來產生顏色。這些蝴蝶翅膀鱗片上的表皮層是由奈微米尺度透明的幾丁質-空氣隔層結構所構成。不同於色素及染料為吸收和反射特定波長的光線，這些多尺度鱗片構造使照射到翅膀表面的光線產生繞射及干涉現象。翅膀鱗片脊狀突起 (ridges) 側面生成的交肋 (cross ribs) 使入射的光波產生繞射，導致光波在穿過這些結構的間隙時散佈。繞射的光線之後互相干涉，導致特定顏色波長互相抵銷（破壞性干涉），而其它則增強並反射（建設性干涉）。翅膀鱗片脊狀突起的高度變化似乎會影響干涉，以致在大範圍角度觀察時，被反射的顏色為一致。反射出來的特定顏色取決於隔層結構的形狀以及它們的相隔距離。蝴蝶能靠這種光線操控的方式造成炫麗的虹光色彩 (iridescent colors)，進行偽裝 (camouflage)、溫度調控以及訊號傳遞。

Many types of butterflies use light-interacting structures on their wing scales to produce color. The cuticle on the scales of these butterflies' wings is composed of nano- and microscale, transparent, chitin-and-air layered structures. Rather than absorb and reflect certain light wavelengths as pigments and dyes do, these multi scale structures cause light that hits the surface of the wing to diffract and interfere. Cross ribs that protrude from the sides of ridges on the wing scale diffract incoming light waves, causing the waves to spread as they travel through spaces between the structures. The diffracted light waves then interfere with each other so that certain color wavelengths cancel out (destructive interference) while others are intensified and reflected (constructive interference). The varying heights of the wing scale ridges appear to affect the interference such that the reflected colors are uniform when viewed from a wide range of angles. The specific color that's reflected depends on the shape of the structures and the distance between them. This way of manipulating light results in brilliant iridescent colors, which butterflies rely upon for camouflage, thermoregulation, and signaling.

文獻引用 (REFERENCES)

「雄性蝴蝶炫麗的虹光色彩賦予長距離同物種溝通的能力，而這種色彩長久以來被相信是由微結構所形成，而不是色素。然而只有少數的研究根據反射及傳遞的強度，以及觀察角度的探討，明確地把鱗片之間的微構造連結到整體的蝴蝶視覺現象 (butterfly visibility) 上。」

「利用聚焦雷射技術 (focused-laser technique)，我們研究了兩個物種藍閃蝶 (*Morpho* butterfly) 單一尺度鱗片結構的絕對反射率及透射率 (absolute reflectivity and transmitivity)，以及它們出色的廣角度視覺現象 (wide-angle visibility) 背後的機制。測量數據顯示部分藍閃蝶微構造能在一個平面中以超過 100 度及另一平面 15 度的角度範圍內，反射高達 75%的入射藍光。」

「我們的結果說明了在一層高度散發虹光色彩的鱗片之上，結合了另一層更加透明的鱗片，會形成非常強烈的繞射，我們推測這種效果有進一步增加入射光反射角度範圍的作用。」

「使用折射率匹配技術測量，所得到構成單一尺度鱗片微構造之角質物質的複合折射系數為 $n = (1.56\pm0.01) + (0.06\pm0.01)i$。這個結果提供了微構造系統理論模型建構時的必要資訊。」(Vukusic et al. 1999: 1403)

「(i) 在脊狀突起中的層狀構造提供了建設性干涉作用，導致選擇性波長範圍的強烈反射。(ii) 脊狀突起的不規則高度，消除了入射光在脊狀突起間的干涉作用，造成統一的顏色擴射及廣角度反射。因此，分隔層狀結構造成的干涉及折射的共同作用，是形成結構色的關鍵…(iv) 脊狀突起的不規律高度亦造成了空間中散射光的偶發干涉，呈現閃閃發光的斑點…」(Kinoshita et al. 2002: 1420-1421)

"Brilliant iridescent colouring in male butterflies enables long-range conspecific communication and it has long been accepted that microstructures, rather than pigments, are responsible for this coloration. Few studies, however, explicitly relate the intra-scale microstructures to overall butterfly visibility, both in terms of reflected and transmitted intensities and viewing angles."

"Using a focused-laser technique, we investigated the absolute reflectivity and transmissivity associated with the single-scale microstructures of two species of *Morpho* butterfly and the mechanisms behind their remarkable wide-angle visibility. Measurements indicate that certain *Morpho* microstructures reflect up to 75% of the incident blue light over an angle range of greater than 100 degree in one plane and 15 degree in the other."

"We show that incorporation of a second layer of more transparent scales, above a layer of highly iridescent scales, leads to very strong diffraction, and we suggest this effect acts to increase further the angle range over which incident light is reflected."

"Measurements using index-matching techniques yield the complex refractive index of the cuticle material comprising the single-scale microstructure to be n=(1.56 plus or minus 0.01) + (0.06 plus or minus 0.01)i. This figure is required for theoretical modelling of such microstructure systems." (Vukusic et al. 1999: 1403)

"(i) Lamellar structure in a ridge offers constructive interference, which results in the strong reflection within a selective wavelength range. (ii) The irregularity in the ridge height eliminates the interference among the ridges, which results in the diffuse and broad reflection of a uniform colour. Thus, the combined action of interference and diffraction due to the separate lamellar structure is essential for the structural colour…(iv) The irregularity in ridge height also results in the accidental interference of scattered light in space, manifesting as the glittering speckles…" (Kinoshita et al. 2002: 1420-1421)

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延伸閱讀

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

https://en.wikipedia.org/wiki/morpho
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撰寫/翻譯/編修者與日期

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AskNature 原文連結

https://asknature.org/strategy/wing-scales-cause-light-to-diffract-and-interfere/