Photophysics of Blue Coloring in *Morpho* Butterflies
- Cooperation of Regular and Irregular Structure on a Scale

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Wings of *Morpho* butterflies are known to exhibit a beautiful blue color and they have been studied for over hundred years. It is generally accepted that the color originates from the interference of light due to a multilayer of cuticle and air. However, the *uniform multilayer model* fails to explain the almost uniform blue color of the wing with respect to the reflection angle, which may be important for the mutual recognition of the species. The electron microscopic investigations have revealed that the multilayer structure is not uniform but discrete to form the ridges spacing roughly 1 μm.

We have performed the detailed investigation on the angular dependence of the reflection of a wing and a single scale of two typical type of *Morpho* species, *M. didius* and *M. sulkowskyi* and have clarified the mechanism of the widespread distribution of blue light. In Fig. 1a, we show the experimental result for a wing of male *M.didius*. It is clear that the blue light of 480 nm is reflected over a wide angular range up to 80^o under the normal incidence, while the violet light of 400 nm is scattered to the direction around 50^o more than 0^o. Considering the real structure of a scale, we propose a new model, which consists of independently built ridge structure with a lamella having several layers. The random distribution of ridge heights is assumed. Then the effect of the discrete lamellar structure provokes the diffraction due to the small area of lamella and the incoherent reflection by the different ridges. We have simulated the angular dependence of the reflected light intensity, which reproduces the experimental data fairly well as shown in Fig. 1b.

In conclusion, both the regular and irregular structure, a mutilayer of lamella and the random heights of ridges, are responsible for the blue color in *Morpho* butterflies. It is also shown that the presence of the pigment in the scale greatly enhances the blue color in some species of *Morpho* butterflies by reducing the randomly scattered light and the transmission from the back.

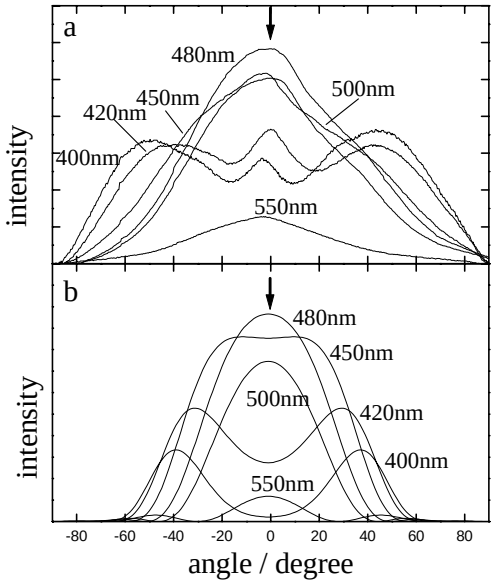

Fig1. a) Experimental and b) simulated angular dependence of the reflected light intensity under normal incidence for a wing of male *Morpho didius* without less-iridescent cover scales.