Butterfly Blue

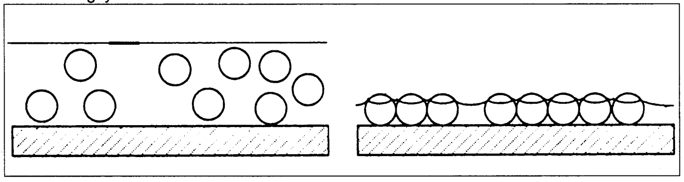
Packaging a butterfly's iridescent sheen

By IVARS PETERSON

A flicker of metallic blue signals the flight of a *Morpho* butterfly. With each beat, its broad wings catch the sunlight, sending a blue spark across a distant clearing in the rain forest.

This eye-catching glint resembles the rainbow-hued iridescence of a soap bubble or an oil slick. But in the *Morpho*, only one color stands out. From certain angles, its wings appear vividly blue. At other angles, they look merely dull brown or gray.

Photos: Nagayama *et al.*



In convective assembly, the evaporation of liquid brings suspended particles (left) close together. When the water film gets thin enough, surface tension pulls the particles into an orderly array (right).

The butterfly's brilliant sheen originates not in a blue pigment but in the microscopic texture engraved on the colorless, transparent scales that cover its upper wing surfaces. Instead of absorbing some colors and scattering others, these surface features reflect sunlight in such a way that light waves interfere with each other, reinforcing blue wavelengths while canceling out the remaining colors.

The spectacular iridescence of *Morpho* butterflies has long attracted attention. In recent years, it has served as a striking example of what can be accomplished without the use of dyes or pigments—a matter of considerable interest to researchers trying to develop alternatives to coloring agents based on toxic elements and compounds.

However, creating the minuscule, extremely regular structures necessary to produce a surface that displays such precisely tuned iridescence is no simple task. It requires large-scale manipulation of materials at a microscopic level.

One potentially attractive approach is to allow the necessary components to organize themselves into the required structures, just as proteins assemble themselves into complex units inside a living cell (SN: 3/25/95, p.186).

A team of researchers in Japan has taken advantage of this kind of self-assembly to produce finely textured surfaces that shimmer with a brilliance rivaling that of the *Morpho*. Consisting of tiny particles arrayed in orderly patterns on smooth glass plates, such surfaces interact with light to create a strongly iridescent effect.

Team leader Kuniaki Nagayama of the University of Tokyo described the novel coating technique used to make these particle arrays at a meeting of the International Society for the Interdisciplinary Study of Symmetry, held in August in Alexandria, Va.

Nagayama heads a project at the Research Development Corporation of Japan in Tsukuba that is aimed at understanding how proteins spontaneously organize themselves into various structures. Through such insights, Nagayama and his collaborators hope to learn how to control and apply these processes in order to fabricate unique materials and objects.

"Our goal is to bring the principles of biological self-assembly into engineering technology," Nagayama says. Eventually, it may even be possible to build things as complex as brainlike computers.

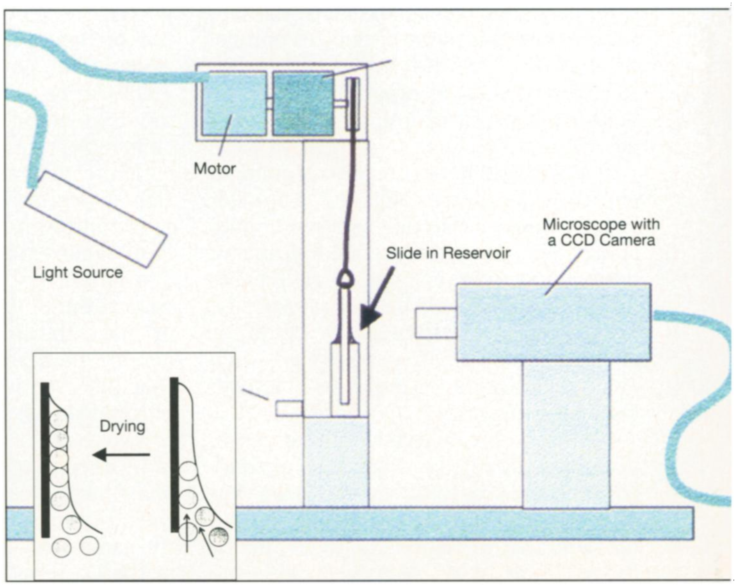
Initially, the researchers focused on inducing small proteins to join together into larger molecular units. These units could then be assembled into a thin film on a surface—in effect, undergoing a form of two-dimensional crystallization.

The simplest way to create such a film is to spread a thin layer of a particle suspension on a smooth surface. As the liquid in which the particles are suspended evaporates, they settle into place on the supporting plate. But they don't necessarily line up in orderly rows spanning wide areas.

A group of chemists from Bulgaria, who had joined Nagayama's project, solved this problem by taking a hint from a demonstration sometimes used to amuse children: Aluminum disks floating on water magically come together to form an orderly, hexagonal arrangement.

Experimenting with tiny, uniform polystyrene spheres suspended in water, the researchers found that the currents created when water evaporates from a layer atop a glass plate bring the particles close together. When the water layer becomes thin enough for the particles to poke through, surface tension takes over, pulling nearby spheres into the regular lattice of a two-dimensional crystal.

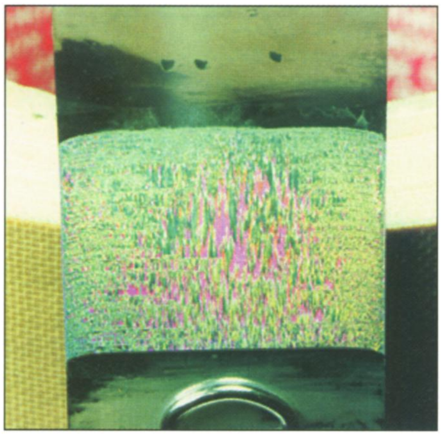
The chemists termed the process convective assembly. The same mechanism underlies scum formation on the walls of swimming pools or in kitchen sinks—anywhere that water laden with dissolved or suspended substances evaporates next to a wettable solid surface.



Schematic diagram of apparatus used to produce particle arrays on solid surfaces. Here, a glass slide is slowly withdrawn from a reservoir containing tiny polystyrene particles suspended in water. Inset: Evaporation of liquid at the air-water-solid interface produces an orderly layer of particles on the slide.

They also discovered that they could control array formation and growth by manipulating the boundary where air, liquid, and particle meet. Thus, when a glass plate is dipped into a suspension of particles, the particles begin to pack together into a single layer near the water-air contact line. Withdrawing the plate at an appropriate rate induces continuous growth of this array.

Using this technique and suspensions of polystyrene spheres ranging in diameter from 0.079 to 2.106 micrometers, the researchers found they could generate various types of textured surfaces.



Glass slide coated with a layer of polysterene particles. The slide is 2.6 centimeters wide, and the particles have a diameter of 953 nanometers.

It was Antony S. Dimitrov, now at the L'Oreal Tsukuba Center in Japan, who first noted that these two-dimensional crystals of fine, closely packed particles also produce beautiful colors, reminiscent of the iridescence displayed by butterflies and other organisms. By changing the particle packings, he could alter the color patterns.

Now, researchers are looking into ways of exploiting this technique for creating iridescent materials that artists and others can use. Moreover, the same technology may prove useful in fabricating diffraction gratings, optical storage materials, selective solar absorbers, and new types of optical filters and coatings—even molecular coatings built out of large proteins.

But these particle arrays don't actually duplicate the way *Morpho* butterflies produce their brilliantly blue glimmer.

A butterfly's wings are covered with scales—the fine "dust" visible with the unaided eye (SN: 6/16/90, p.376). Observed through a microscope, however, the tightly packed rows of overlapping scales look very much like shingles on a roof.

In *Morpho*, a set of microscopic, evenly spaced, parallel ridges runs the length of the scales. Each ridge has furrowed sides; a cross section of the ridge would resemble a neatly branched Christmas tree. It is the reflection of light from these precisely spaced, overlapping projections that gives rise to the optical thin-film interference responsible for the butterfly's iridescent blue.

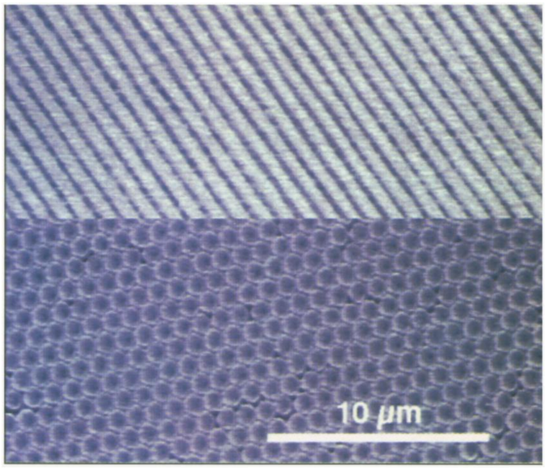
"The precision is extraordinary, very sharply tuned to a particular wavelength of light," says entomologist Thomas Eisner of Cornell University.

Each millimeter of wing surface has about 15 scales, with dozens of ridges on each scale. A ridge typically has about 15 longitudinal branches, all uniformly spaced and each one no thicker than a fraction of an optical wavelength. It takes millions of these layered projections to give *Morpho*'s wings their distinctive glitter.

No one knows how a scale cell manages to secrete and assemble such elaborate and delicate structures. However, the material involved has some of the characteristics of ordinary plastic, which, when stretched and stressed, readily buckles into a wavy shape.

"I've studied the development of scales," says Helen Ghiradella of the State University of New York at Albany, "and elastic buckling is about the best explanation that I've been able to come up with so far."

At the same time, *Morpho*'s wing scale architecture is only one of an incredible variety of scale formations observed in butterflies and moths.

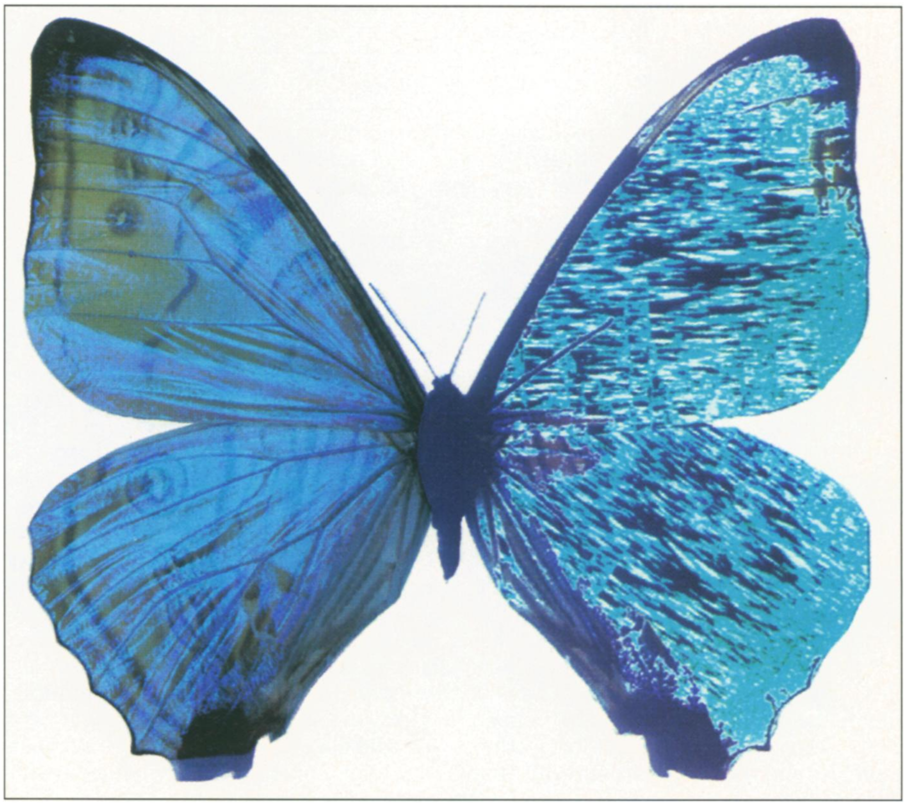


Electron microscope images showing parallel ridges on a scale from a butterfly wing (top) and a particle array on a glass slide (bottom).

Several years ago at an Optical Society of America meeting, Ghiradella described structural colors in Lepidoptera as a particularly striking example of precision in biological pattern formation.

"Many of us working in biological fields have perhaps unconsciously assumed that small things must be simple—at least more accessible to human understanding than those at human scale," she concluded. "This may not be the case; and indeed, the further we investigate, the more complexity we seem to find."

The architecture of iridescence, so brilliantly exploited by the *Morpho* butterfly, calls attention to this creature of the rain forest—not only for its beauty but also for the lessons it may hold for human constructors. □



The delicate blue iridescence of the wing of a Morpho sulkowskyi *from Peru (left) is compared with the color of a "wing" constructed from tiny particles arrayed on a supporting surface (right).*