Material ConneXion®
A SANDOW Company

101 Material Report

Structural Color

What you need to know

Surfaces can exhibit many visual attributes that include color, pattern, texture and 'special effects' such as interference and pearlescence. These effects are created by a combination of pigmentation and depth and pattern of roughness. This report takes a look at color and how it is produced. Color as an attribute is actually quite deceptive. Through this report Material ConneXion would like to provide a brief overview on how objects have their characteristic color, but with a special focus on structural color and why it matters. Additionally, through this we will also briefly discuss some effects which include iridescence, and dichroism.

01 What is color?

The colors that are perceived everyday are a result of specific 'light – material' interactions. The common perception is that the phenomenon of color occurs due to a pigment or dye that is used to stain fabrics and surfaces. While this is partially true, color is so much more. The sun's rays, which is white light, contains all the colors of the rainbow mixed together. When light falls on an object, some colors bounce off and other are absorbed. So, for example, a red inflatable pool toy contains a red pigment in the PVC it is made from. This red actually absorbs every color of the spectrum except red, which is bounced back into your eye. Color can also be created through an interference and preferential scattering process of the surface, so that rather than having a particular pigment create the color, it is achieved by scattering the light so that only certain wavelength, which will be the main focus of this report.

02 Structural vs. Chemical color

Color can be applied or created onto surfaces in two common ways: either chemically or structurally. Chemical processes to create color can either be through the use of dye inks or pigment inks. This form of color is either incorporated within a surface (dyes) or onto a surface (pigments). Structural color, in contrast arises from the physical interaction of light with biological nanostructures. Light is preferentially scattered by surface structures, meaning the scattering process favors particular colors (interference) and picks out specific colors from the full spectrum of sunlight or white light (selective absorption).

Structural Color

Bright blue butterflies and berries that look fresh and iridescent for over a hundred years have something in common. Both these seemingly everlasting colors are due to structures on the surface of the butterfly wing and berry respectively. This section investigates what structural coloration is, with a focus on why it matters and how to implement the same.

What is it?

Structural color is a form of light-material interaction caused by schemochromes which are colorless nano-structures on the surface of organisms that serve as a source of color by the manner in which they reflect light.

How does it work?

Various structures can accomplish creating bright and vivid colors such as ridges, striations, facets, successive layers and other randomly dispersed light scattering bodies.

Why is it important?

Fading or photochemical degradation is a significant concern with chemical or pigment and dye based color. Another concern that can influence the applications of chemical color is its potential toxicity. With the use of chemicals, there is always a concern about the constituents of such dyes and pigments and their safety. Structural color has been gaining attention due to these very reasons; with no chemicals causing color, there is no concern about the safety and toxicity of structurally colored surfaces or products. Additionally, structurally colored surfaces are highly durable and do not fade with time. Such color will effectively last till the surface in question is completely abraded.

How do we implement it?

Structural coloration widely occurs in nature. Structural modifications in organisms that display structural coloration are genetically encoded, hence replicating this phenomenon might seem like a highly complex process. Technology however has ensured that this process can now be reproduced to a certain extent through two either a top down or a bottom-up approach. Top-down approach: This approach primarily involves sculpting or writing a nanostructure on a surface by physically removing materials from the surface. Bottom-up approach: The bottom-up approach simulates growth. It involves the hierarchical creation of nanostructures through self-assembly of building blocks.

When Light Transforms Into Art

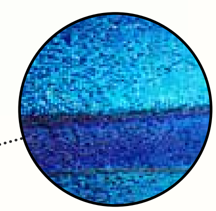
What gives the blue morpho butterfly such particular hue if no blue pigment is involved?

Butterfly wings are composed of scales. Each scale constitutes one cell. Their dimensions are at least 15 times bigger than the average human red blood cell.

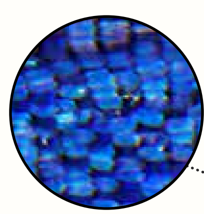
Interference of light

When light hits a surface and bounces off to our eyes, light waves reflecting from the upper or lower side of the surface will interfere with each other. When two light waves add to form a bigger wave, this is known as constructive interference.

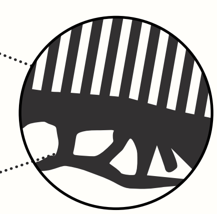
Nanostructures in the upper side of the butterfly wing are responsible for constructive interference specfically to reinforce blue light. The underside of the wing is colored by brown, yellow and black pigments. The pigment absorbs unnecesary green to red light enhancing the contrast of blue color.



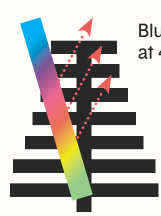
A. Scales are organized in overlapping rows, like tiles on a roof.



B. Each scale is composed of thousands of ridges.



C. Ridges in each scale are composed of nanostructures (pine tree shaped) that confer the blue color.

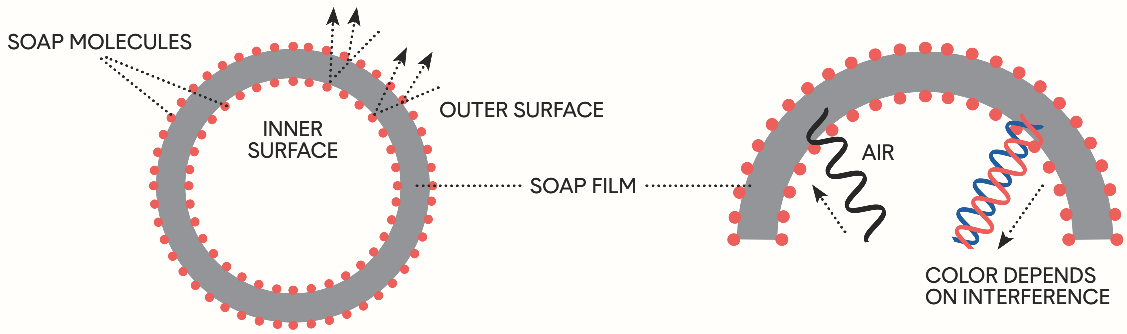


PIGMENT

D. Multilayer interference occurs in each layer of the pine tree shaped structure reinforcing the wavelength of blue light that our eyes perceive.

Iridescence

Soap Bubble



What is it?

Iridescence is a unique property of structural color. Chemical or pigment based colors differ from structural colors in the patterns that they produce. Chemical colors are most often diffuse, meaning they look the same from all angles. Reflective structures on the other hand can preferentially scatter one color at a particular angle and another as the angle shifts. This phenomenon of different colors appearing at different angles is called iridescence. The term is derived from the Greek word 'iris' meaning rainbow, referring to the multicolored visual appearance that such surfaces have. Iridescence is seen in a variety of objects and surfaces such as CDs, soap bubbles and even peacock feathers.

How does it work?

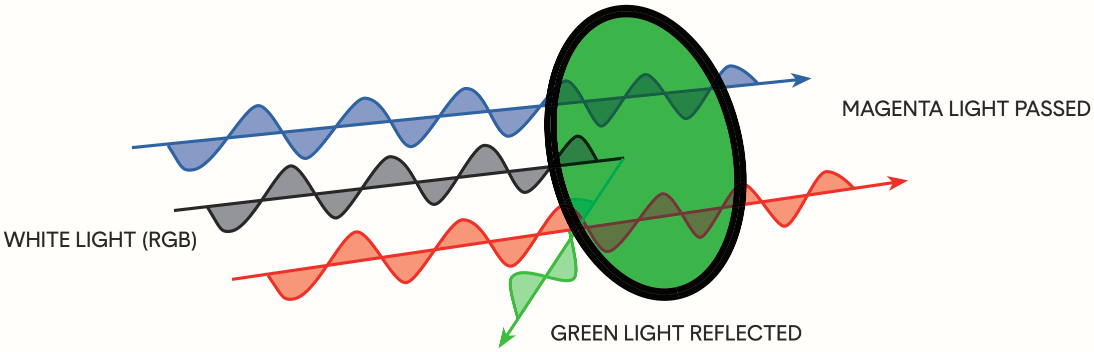
Iridescence can occur through multiple mechanisms. Soap bubbles and oil films for instance exhibit iridescence due to differences in film thickness, which affects how light bounces off the surface. Compact discs (CDs) on the other hand are iridescent due to light falling on minute slits or spaces on the surface of such materials. Nanostructures, as in the case of structural coloration can also cause iridescence as seen in peacock feathers, which again splits and partially scatters light. The essence of iridescence is that light falling on a surface from different angles causes the surfaces to appear multicolored.

How do we implement it?

Iridescence can be created either through the addition of metallic compounds to surfaces or through structural methods. For example, metallic compounds can be used to create iridescent paints and powders. For metallic substrates, metal anodizing can also be used to create iridescence. This process can create bright iridescence with a metallic luster. For plastic, paper and other materials iridescence films and spray coatings can be applied.

Dichroism

Magenta Interference Filter



What is it?

Literally meaning 'two-colored' the concept of dichroism comes from minerology. Some minerals have different colors when they are viewed from different axes. Through dichroism, two colors are seen. A surface or material is said to be dichroic if it splits white light that falls on its surface in such a way that it appears to be of a particular color, but it transmits light of another color through it.

How does it work?

Dichroism, works in a similar manner as iridescence. In iridescence, where multiple colors are observed when light falls on a surface, dichroism controls this process, allowing for only two colors to be seen. One color is seen on the dichroic surface, the other color is seen as light transmits through the dichroic surface and casts a shadow. Dichroism can be of two types, either as dichroic filters or dichroic reflectors.

How do we implement it?

In glass substrates and dichroism is created by deposition of ultra-thin layers of different metals or their oxides. This is in the form of a coating. Dichroic films are also available which can be applied on a variety of substrates such as glass, polymer or even polished ceramic and cement-based materials.

Summary

Structural color, though common in nature, is much less prevalent in our products. Despite its many advantages over chemical color, there still remain technical and economic barriers to its more widespread adoption. Innovations in this area are making the technology more accessible and it is expected that more surfaces will be colored in this way in the future.

References

Learning Guide

Learning Guide

Materials relevant to this report

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