da Vinci's notebook

da Vinci's Notebook, vol. 2 (2010)

How Nanoscience Allows for Iridescence in Nature

Josh Fisher
First-Year Student (B.Sc. Nanoscience)
College of Physical and Engineering Science, University of Guelph, CANADA

Butterflies of the genus *Morpho* have brilliant blue wings that are both aesthetically pleasing and function as a defence mechanism; to accomplish this, these butterflies harness nanoscience and an optical phenomenon known as iridescence. Iridescence is an example of structural colour that is produced by the interaction of the physical structure of the surface with light. In 1704, Sir Isaac Newton published his book *Opticks*, in which he hypothesized about how organisms in nature, such as peacocks exhibited iridescence (Vukusic & Sambles, 1998; Kinoshita, Yoshioka, & Miyazaki, 2008). Now, hundreds of years later, nanoscience enables an in-depth understanding of how such optical phenomena occur. Specifically, through studying butterflies belonging to the genus *Morpho*, one is able to investigate the nanotopography of wings to determine how thousands of intricate nanoscale structures function to give *Morpho*s the brilliant blue wings that are capable of making predator birds dizzy. The explanation of this effect can be found in Bragg's Law of Diffraction (ONeill, 2009)**,** and can then be applied to photonic crystals as well as the understanding of the phenomenon of iridescence in general.

When one sees the green leaves of a plant, and then the brilliant blue iridescent wings of a *Morpho* butterfly, they are in fact observing two different kinds of colour. The two main types of colour are chemical colour and structural colour. When one observes the green colour of a plant's leaf, they are observing chemical colour. This colour is determined by pigments that absorb certain frequencies of light while reflecting others. On the other hand, the brilliant blue iridescent wings are an example of structural colour, which is determined by how physical structures on the nanoscale interact with light in the visible region of the spectrum, which consists of wavelengths of approximately 400 nm-700 nm (Vukusic, 2008). Different interference patterns are created as light passes through the structures. Destructive interference will take place when the path difference of the light scattered from neighbouring points causes a phase shift that is not an integer number of wavelengths, so that neighbouring rays are not in phase with each other, causing the light intensity to dim or even disappear. Constructive interference occurs when the path difference of light causes a phase shift that is an integer number of wavelegnths, resulting in an even brighter colour since they are in phase with each other. The shade of iridescence changes depending upon one's orientation with respect to the light scattering surface. This phenomenon is also explained by Bragg's Law of Diffraction, which is "expressed as: $n \lambda = 2d \sin\Theta$ where n (an integer) is the "order" of reflection, λ is the wavelength of the incident [light], d is the interplanar spacing of the crystal and Θ is the angle of incidence." (ONeill, 2009). When Bragg's law is satisfied at a certain angle, constructive interference in light of a particular wavelength occurs. Therefore, since iridescence depends upon the constructive interference of light, depending upon variables including one's angle of view, iridescence of a particular light wavelength (colour of light) can occur. In nature, a species must possess specialized nanostructures in order for iridescence to occur.

The wings of *Morpho* butterflies contain many intricate nanostructures that enable iridescence. Each wing contains thousands of layered scales. When one takes a closer look at the nanotopography of these scales, it becomes evident that each scale contains an even greater number of intricate structures, consisting of multiple layers of longitudinal ribs called "setae." These setae are covered in chitin ridges called "cuticle" that consist of chitin polymerized from glucose. The setae form branched structures which are transparent and separated from each other by small air filled gaps (Vukusic, 2008). These structures create a magnificent blue iridescence. For example, the male *Morpho rhetenor* is "capable of reflecting 80% of the incident light at the blue wavelength" (Vukusic, 2008, p. 732). When light hits the setae branches, some light is reflected while some makes its way through to the cuticle. Lower branches of setae are also able to function as a scattering surface since they stretch out further than the higher branches (Vukusic, 2008). Together, the branches and their alternating cuticle/air gaps allow for diffraction and the destructive interference of most light wavelengths. However, constructive interference occurs in light of blue wavelengths with the end result being the brilliant blue colour of the *Morpho*'s wings. Iridescent properties can also be attributed to the nanostructure of photonic crystals which have the ability to alter the passage of light rays by diffraction (Roduner, 2006).

The iridescence found in peacock feathers has been examined by many scientists including Hooke, Newton, and Mason (Kinoshita et al., 2008). It has now been attributed to structures that modify the passage of light rays. Durer determined in 1962 that peacock feathers contain barbules made up of a series of melanin rods (1 micrometer in length) which have a distance "separation [that is] perpendicular to the surface correlated with the apparent colour of the feather" (Kinoshita et al., 2008). This structure is mimicked by synthetic photonic crystals, which, generally speaking, contain nanosized periodic structures that are capable of causing diffraction effects, including the constructive interference of certain light wavelengths, resulting in iridescence.

Nanoscience has increased the understanding of the *Morpho* butterfly's wing structure, of peacock feather structure and of photonic crystals. These discoveries have allowed for the production of photonic crystals so that they may be used in a variety of future applications. Some potential applications include wrapping foils, decoration paper, hair sprays and, nail polish (Roduner, 2006), as well as thin films for anticounterfeit protection, and light emitting diodes and photonic crystal lasers (Cao, 2004). The textile industry has already managed to mimic aspects of the *Morpho*'s wing structure however and to create a new pale blue iridescent fabric. The fabric is a multi-layer construction containing similar refractive indices: 61 layers of nylon 6 (n=1.60) and polyester (n=1.55), each with a thickness of about 70-90 nm (Kinoshita et al., 2008). These applications may even find that "photonic crystal diodes and transistors will eventually enable the construction of an all-optical computer" (Cao, 2004, p. 409).

Through the use of thousands of layered nanostructures, *Morpho* butterflies are able to defend their territory and themselves from predators. Light of blue wavelengths coming into phase through constructive interference create a magnificent blue that is capable of intimidation and confusion of other organisms, and peacocks are able to harness the barbule's structure of their feathers for a similar purpose. Now that nanoscience has allowed for a better understanding of how nature harnesses structural colour and iridescence in particular, an entire new field of research is opened up. Thanks to this area of research, one may soon be seeing the mimicking of nature's iridescence in order to improve our everyday lives.

REFERENCES

Cao, G. (2004). *Nanostructures & nanomaterials: synthesis, properties & applications.* London: Imperial College Press.

Kinoshita, S., Yoshioka, S., & Miyazaki, J. (2008). Physics of structural colors. *Reports on Progress in Physics, 71,* 076401 doi: 10.1088/0034-4885/71/7/076401

ONeill, F. (2009). *Bragg's Law: X-ray fluorescence and nature's Iridescence*. Retrieved December 10, 2009 from UIS Analytical Services website: http://www.uis-as.co.za/index.php?option=com_content&task=view&id=112&Itemid=2

Roduner, E. (2006). *Nanoscopic materials size dependent phenomena.* London: RSC Publishing.

Vukusic, P. (2008). Natural Nanomaterials. In G.L. Hornyak (Ed.), *Introduction to Nanoscience (pp.730-734).* Boca Raton: CRC Press.

Vukusic, P. & Sambles, J.R. (1998). *Iridescence in lepidoptera*. Retrieved December 10, 2009 from University of Exeter, Electromagnetic Materials Group website: http://newton.ex.ac.uk/research/emag/butterflies/iridescence_in_nature.html