By Tony Klein
The University of Melbourne - Australia
DOI: 10.1051/epn/2014301

The lustre of pearls

About 15 years ago, I learned from a gemologist friend that the value of pearls is appraised by evaluating the following factors: Size; shape; colour and lustre (a term used for the quality of shinyness). The first three are easily quantified, but what about lustre? I decided to look into the problem as an intriguing piece of applied optics.

Pearlescence? Iridescence? What optical phenomenon is responsible for the unique appearance of nacre (*i.e.* mother-of-pearl)? The appearance of abalone shell, especially New Zealand Paua shell, gives a clue: Interference colours. So it must be something to do with the structure, maybe it is due to something like thin film interference?

This is confirmed by scanning electron microscopy- see Fig.1 – and explained by marine biologists as follows: Nacre consists of thin, tabular crystals of aragonite, which is Calcium Carbonate that the mollusk concentrates from seawater. But that is not all: aragonite normally forms needle-shaped crystals. However in seashells, it is constrained into tabular, platelet-shaped crystals by means of a protein secreted by the animal. This protein has dangling bonds with a spacing that is comparable with that of calcium carbonate molecules arranged in flat layers.

Cartoon by Melbourne artist Leunig

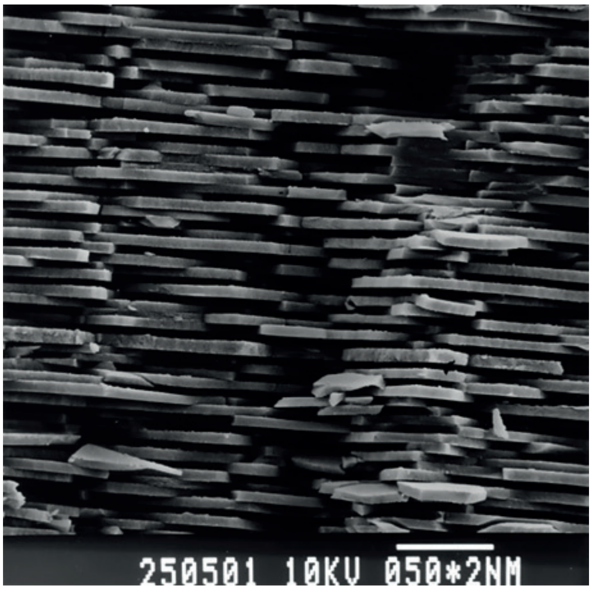
So the biology of the situation constrains a change in crystal 'architecture' – from acicular, *i.e.* needle-shaped, to tabular. This, incidentally, gives the resulting composite structure quite remarkable mechanical strength, apart from the interesting optical properties.

That seems to explain it, I thought: In abalone shells, the thickness of the "bricks" must be very uniform so that thin-film interference gives rise to iridescent colours. But what about ordinary nacre (mother-of-pearl) and indeed pearls themselves?

My first thoughts were that maybe the layers are too thick or maybe of non-uniform thickness in ordinary nacre. I wasted a lot of time trying to calculate the reflection properties of thin films of slightly variable (*i.e.* poly-disperse) thickness. This turned out to be an interesting exercise, rather more difficult than I thought. I even enlisted the expert help of Professor John Lekner from Victoria University, New Zealand, who spent a brief Sabbatical with us in Melbourne and is a noted specialist in reflection phenomena, random matrices and so forth. It turned out to be a wild goose chase and eventually the real answer dawned on me and turned out to be much simpler than I had thought.

Before coming to the real explanation, I must remind you why sugar, salt, snow, *etc.* are white. Rather surprisingly, many students and even more accomplished physicists are unaware of the answer. Starting with an analogy, the random walk of a drunk near a cliff-top, even if initially stepping away from the cliff face, inevitably ends up at the bottom of the cliff! In a completely analogous way, a photon (or a ray, if you prefer) entering a substance consisting of small transparent crystals gets randomly refracted (scattered) and ends up coming back to the surface, whence it emerges in some random direction, never to return to the bulk. This is a form of diffuse reflection, which – if the crystallites are totally non-absorbing – corresponds to 100% reflection. Even better than the best metallic mirrors! So, a white surface is a better reflector than a metallic surface. Even with a certain amount of absorption caused by impurities, this gives rise to strong diffuse reflection, hence the utility of white paint. The mean depth to which the photon (or ray) penetrates depends on the scattering power of the crystallites. This, in

Article available at http://www.europhysicsnews.org or http://dx.doi.org/10.1051/epn/2014301



▲ **FIG. 1:** Scanning Electron Micrograph of a broken surface of abalone shell (Courtesy Dr R. Day, University of Melbourne).

practice, depends on the refractive index, which determines the deviation at the interfaces between the crystals. Hence, Titanium Dioxide, a material with a high refractive index, when finely powdered and suspended in a transparent carrier, makes an excellent white paint, better than Lead Oxide paint or Zinc Oxide in paint, which have smaller refractive indices and hence not as good a "covering " power. This is "the physics of paint" – apart from a supplementary section on selective absorption in pigments, which also consist of crystallites that are transparent, and hence diffuse reflectors in selected wavelength bands.

Now back to the problem of lustre. It's simple! Imagine a photon incident on the surface of nacre. It gets scattered, *i.e.* refracted at each crystal interface, deviated before being incident on the interstitial layer of protein and scattered again and again eventually emerges from the front, just like from a surface of sugar, salt *etc.* – but with a major difference: The "random walk" that it executed is highly anisotropic: It travels much further in the lateral direction, along the tabular crystallites, rather than the thin, normal direction, before re-emerging. Thus it emerges much further from the point of incidence than it would have from a substance made of isotropic crystal grains. The net result, if you think about it, is that the splash of light reflected from the surface is much greater than it would otherwise be from, say, white paint *etc.* There is just a little more to it than that: It turns out that, in the case of spherical pearls, the crystalline platelets tiling the surface follow the curved surface so that the light diffusing sideways actually follows the contour of the surface and makes it more luminous than an isotropic scatterer. All this, therefore, creates the illusion of being whiter than white, thereby explaining why it is 'lustrous'!

Artists such as the famous Dutch Master Johannes Vermeer (1632 – 1665) must have realised this – see Fig. 2 – "The Girl With the Pearl Earrings". The pearl is painted as much whiter than other white surfaces in the picture.

I was quite pleased with myself when I succeeded in explaining the nature of "lustre" – at least to my own satisfaction – as diffuse reflection from a stratified, anisotropic material. But then I realised that something as simple as that must have been discovered by others before me. Indeed that is the case: It's all there in the Scientific Papers of that doyen of light scattering, C.V. Raman (Indian Acad. of Sci. 1988 Vol. IV, 256; *The Optics of the Pearl*, 1954).

By the way: the paint industry woke up to this too, when it started to manufacture iridescent paint incorporating finely ground mica platelets, for use on luxury cars.

All this reminded me of a cartoon by Melbourne cartoonist Leunig, showing a sad little fellow looking at a sign that says "Go back. It's all been done before!" ■

About the Author

Emeritus Professor **Tony Klein**, held a Personal Chair at the University of Melbourne (1983 – 1998) and is a Fellow of the Australian Academy of Science and a Foundation Member and a Past President of the Australian Optical Society.

▼ **FIG. 2:** "The Girl with a Pearl Earring" by Johannes Vermeer (1632 -1664).