PALMER LAB: Synopsis of Research

We are a multidisciplinary group sitting at the interface between materials chemistry, cell biology and optics. We investigate how animals use highly reflective crystals to manipulate light to produce colors and in visual systems.

Optically-Functional Organic Bio-Crystals

Many optical phenomena in organisms are produced by the interaction of light with assemblies of highly reflective organic crystals. However, despite their widespread distribution in animals little is known about the structure and properties of these materials. Now, the study of biologically-formed organic crystalline materials (‘*Organic Biomineralization*’) is emerging as an exciting new discipline alongside the parent field of *Biomineralization*. It is well-established that high refractive index guanine crystals produce iridescent structural colors in animals such as fish, spiders and crustaceans. Crystalline guanine is also utilized to construct mirrors in animal eyes used for image-formation and enhancing photon-capture. A common motif for guanine-based reflectors is that of multilayer stacks of plate-like crystals interspersed with cytoplasm in the form a Bragg reflector. Reflectivity is produced by constructive interference of light reflected from the high/low refractive index interfaces.

Theme 1: Biological Crystallization Mechanisms

By controlling the structure, morphology and organization of organic crystals, animals produce a raft of different optical 'devices'. A key question is: how do organisms exquisitely control the crystallization of the component organic molecules? We aim to unveil biology’s crystallization tricks which are far superior to *state of the art methods* in solid state chemistry. To explore this question, we follow crystal formation processes in a range of model organisms undergoing development or regeneration. We study changes in crystal morphology and organization using cryogenic electron microscopy techniques, observing the biological tissues in their fully-hydrated, native state. *In situ* diffraction and spectroscopic tools are used to determine changes in the physical and chemical properties of the crystals during growth. Information from these approaches are then synthesized to gain insights on biological crystallization mechanisms. Our ultimate objective is to understand the underlying biological control behind these crystallization processes. Thus, we utilize genetic molecules to correlate gene expression with specific crystallization events during formation. We aim to reveal the key proteins and enzymes involved in initiating nucleation and directing crystal growth.

Theme 2: New Biogenic Crystals with New Optical Functions

To date guanine crystals have been found in at least 7 animal and plant phyla. However, aside from guanine, few other functional biogenic organic crystals have been reported, and those that have been are often poorly characterized. In recent years, two 'new' biogenic crystals, isoxanthopterin and 7,8-dihydroxanthopterin were reported in reflective structures in the eyes of shrimp and fish. These molecules belong to the pteridine family, which previously were thought to act exclusively as absorbing pigments in nature. These findings, together with other evidence in the literature suggest that there are many more organic bio-crystals 'out there' to be discovered. This part of the group studies the materials chemistry of unexplored photonic structures in animals, where the identity and properties of the underlying optical materials are not known. We use *in situ* synchrotron X-ray diffraction, electron diffraction and electron microscopy to characterize the structural and optical properties (e.g., crystal structure, crystal habit) of the component materials in these systems. By coupling this information with optical calculations and measurements (e.g., refractive index and reflectivity) carried out in collaboration with Prof. Dan Oron, Weizmann Institute of Science, we can rationalize the amazing optical properties of these biological photonic systems.

As well as being of fundamental interest, biogenic organic crystalline materials have the potential to inspire a new generation of bio-inspired and bio-friendly organic optical materials such as non-fading pigments, photonic paints and digital display materials.