Chemistry of Light and Mater

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A leading optical artist, Victor Vasarely[1] envisaged 'Chaque forme est une base pour la couleur, chaque couleur est l'attribut d'une forme' means 'every form is a base for colour, every colour is the attribute of a form' and incorporated inseparable form and colour in his canvas the way we see light and colour are indivisible in nature (**Figure 1**). Light is the most powerful "entity" in this universe and throughout history our lives have been defined and redefined by light for many times from the formation of oxygenic atmosphere more than 2.7 billion years ago to the guiding of our adventure to see the [2] "two universes". Only light can make us visible to ourselves, give us wide field–of–view, make our communications faster, and solve our energy and fuel problems. It is an infinite source mentioned in the Upanishad "*Purnasya purnamadaya purnameva vashishyate*" means "when the whole is taken out of the whole, the whole still remains whole". Although the importance of light–life interactions was perceived more than three thousand years ago in Egypt at the time of Akhenaton[3] (**Figure 2**), the pursuit to understand the complex nature of light-matter interactions is still in its infancy. How this transcending and mighty power of light is shaping our life through its intimate interactions (chemistry) with matters will be an interest for my essay.

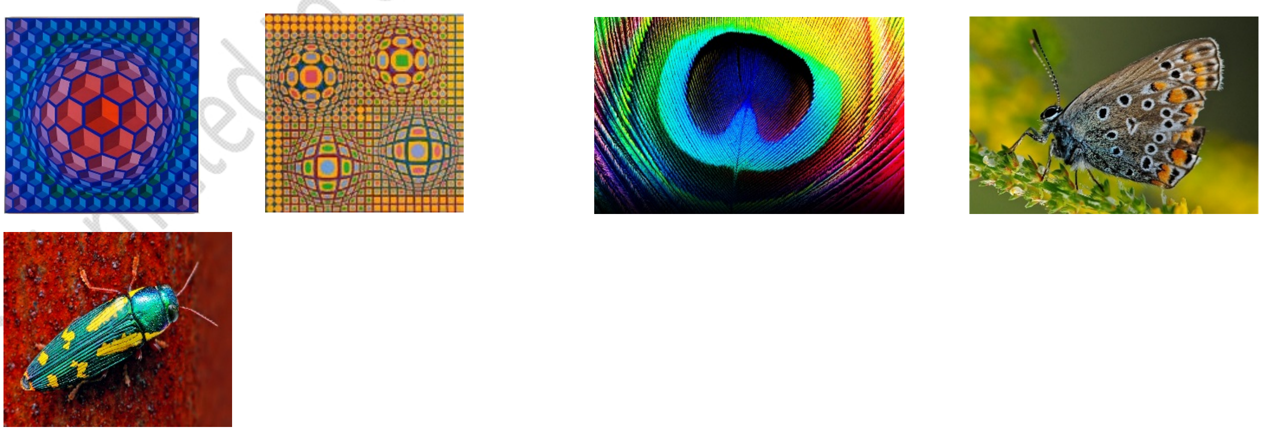

Figure 1. Light and mater interaction in painting (first two) and in nature (wings of peacock, butterfly, and exoskeleton of beetle). Photo-credit: Wikipedia commons

Figure 2. Light–life interactions in Egypt at the time of Akhenaton.

Light-mater chemistry in quest of making optical crystal

Spontaneous pattern formation is abundant in nature, which generates striking patterns in different landscapes including random and ordered strips and spots in animals, birds, fishes, floating clouds, minerals, deserts.[4] Pattern formation generally originates from complex nonlinear processes. The science of nonlinear light propagation requires looking into the fact, how well the host medium (matter) entraps the beams of light (guest) and how they (the host and the guest) undergo mutual changes. In other words, how the beams modify the characteristics of the medium, and in turn how the medium shapes the structure of the beams and in certain cases, forms optical pattern as a result of this dynamic relationship.[5] Interestingly, nonlinear photoresponsive media can suppress the natural broadening tendency (diffraction or dispersion) of light. This is because certain nonlinear media can adjust its refractive index while exposure to light beams in such a fashion that the broadening tendencies (dispersion or diffraction) are counterbalanced. At the same time, the beam of light induces a waveguide in the nonlinear medium and proceeds as a self-guided beam, sometimes known as soliton, towards its propagation without any diffraction.[6]

Numerous studies have been focused on the nonlinear phenomena of temporally and/or spatially coherent laser light (waves of the same wavelength and strong correlation) for more than 40 years. However, it was a challenge to understand the nonlinear light propagation with white light as this consists of different wavelengths and has poor correlation. In 1997, Mitchell and Segev published a seminal paper where they first experimentally observed that white light (a spatially and temporally incoherent source) can be self–trapped in a nonlinear photorefractive medium.[7]

This study opened a new avenue of nonlinear optical research. This approach also inspires other groups to study the nonlinear phenomena with different approach where they started using photochemical medium for self–trapping the white light instead of conventional nonlinear media.[8] Their findings unveiled that this new photopolymerisable organosiloxane based material can also self–trap the white light and can produce some beautiful spontaneous pattern and 3–D optical lattice.

However, some fundamental open questions are still not answered (i) how we can tune the dynamics nature of the self-trapped beams by altering optical intensity or the concentration of polymerizable groups (ii) how these beams behave with each other, whether they are passionate or repulsive to each other or have both qualities at the same time with mutual existence (husband-wife relations). In addition, whether theses beams are eager to form extended family by integrating multiple beams or they like to live as a nuclear family (iii) how the energy, structure and spectral profiles of the self-trapped beams change along with this interaction (iii) how we can modify the nature of symmetry and periodic pattern of 3–D optical lattice by changing the relative angles, incorporating additional beams, and examining other photochemical media.[9]

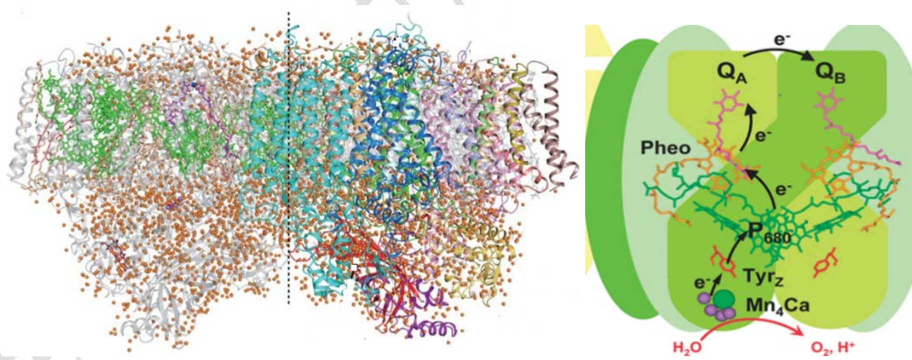

Figure 3. Dimer (left) and photosynthetic process (right) in Photosystem II. Images reproduced with permission from Macmillan Publishers Limited and American Chemical Society.

Light-mater chemistry for solar energy conversion

Our energy consumption heavily relies on fossil fuels. However, these fuels have been viewed as a major environmental threat because of their substantial contribution to greenhouse gases. One of the most promising sustainable sources of energy can be achieved by the photosynthetic process, where in the presence of chlorophyll and other accessory pigments, plants and some bacteria capture photons and convert water and carbon-dioxide into energy-rich organic compounds (**Figure 3**). The whole process is carried out by two photosystems in the thylakoid membrane of plants, marine algae, and bacteria. These complex photosystems are composed of Mn-cluster based redox sites for water oxidation, light harvesting antenna, reaction centre, and energy/electron transfer systems. In the 1990s, when researchers solved the crystal structures of the light harvesting antenna complex from photosynthetic bacteria and plants, the concept of artificial light harvesting opened a new window for solving our energy problems.[10]

Despite numerous studies on this research, still our understanding of natural photosynthetic process requires more insights how the light harvesting complexes interact with each other, and how they perform *a function like rectification, amplification, or feedback*.[11] The impact of the environment on the energy transfer including how the environment and electronic systems interact are not well understood. More studies are required to unveil the interactions of chromophore and solvent medium for the photosynthetic proteins.[12] The questions remained on the function of the protein framework on maintaining the quantum coherence/decoherence are not solved yet.[13] In addition, studies require on how we can synthesis and design well-defined chromophores' arrays connecting them in a rigid framework (in order to avoid the conformational changes and reduce quantum decoherence induced by environment) and optimize them as a small part of a larger light-harvesting system.

Epilogue

Unravelling the chemistry between the non-linear materials and light can assist us to develop some devices for artificial compound eye to make us more visible, for photonic crystal fibre to speed up our communications. In addition, unfolding the quantum phenomena in biological photosystems can shed light to design smart artificial light harvesting devices for solving our energy issues.

References:

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