

Preface

In recent years, structural colors have attracted much attention in a wide variety of research fields. This is because they are originated from complex interactions between light and sophisticated microstructures created in the natural world. In addition, their inherent regular structures are one of the most conspicuous examples of the nonequilibrium order formation. The structural colors are deeply connected with recent rapidly growing fields of photonics. Their mechanisms are, in principle, of a purely physical origin, which differ considerably from the ordinary coloration mechanisms such as in pigments, dyes, and metals, where the colors are anyway produced by virtue of the energy consumption of light. Since the first scientific descriptions on structural colors by Hooke in 1665, a tremendous number of research objects have been investigated using various scientific methodologies. I was somehow trying to summarize this entangled research field, which expanded over many research fields in biology, chemistry, physics, and engineering. It was when a publisher proposed me to write a book on this topic.

I began collecting papers and books on structural colors, which were soon found to be more than 500. Seeing these materials, I felt bewildered because too many research objects in a diverse world of nature were reported, in which most of them were far from clarifying their mechanisms. Most of the books or review papers appeared so far classified the structural colors through their mechanisms and took some species as the typical examples. I thought it difficult to follow this way because the mechanisms for most of the species were completely unknown or only partly known.

I decided to write this book on the basis of species and not of the mechanisms. In order to do that, however, it was necessary to know the kinds of species that have been investigated for these 350 years as the research

objects. My student and I picked up all the scientific names appearing in the papers, and after revising them to current names, listed up according to the current classifications. It was really hard work for us (two of these results, butterflies and birds, are listed in Appendix A). After the classification was completed, I selected lepidopterans, beetles, birds, fishes, and plants as the main objects. Particularly, as the number of the researches concerning *Morpho* butterflies appeared extraordinarily large, I selected them as special objects to give a detailed description on this subject. In spite of that, some of the topics, such as moth-eye structure, had to get over the frame of classification. Moreover, in case of biological reflectors, which will occupy an important part of structural colors, I had to omit those related to vision, because they were too diversely distributed in animal worlds and also the vision itself was one of the largest research fields, which I felt exceeded the scope of this book. In a similar sense, we had to omit interesting descriptions concerning minerals and fossils, and also marine and atmospheric phenomena. If I get a chance again, I would like to write a continuation of this book in future.

According to the above policy, I began to write the manuscript and soon found it really difficult, because most of the research fields were actually unknown to me and I had to write without any real feeling. Then, in each field, I had to learn the classifications, fundamental concepts, and proper technical terms. The language problems sometimes became a large barrier. Further, species picked up in the papers were often completely unknown to me. Hence, I had to order a lot of books and also search over the Internet. Sometimes I went to zoological gardens, aquaria, and repositories of the museums to see real objects. However, I do not deny that many parts of this book were anyway borrowed from excellent papers and books published so far and that the misunderstandings of the contents will be anyway present. Thus, I strongly recommend that if one wishes to investigate the phenomena more deeply, he should read the original papers thoroughly. In spite of that, I am still satisfied with this book, because through the above policy, it becomes possible to write the whole story for each species.

As a physicist, I had a wish to write the physical basis for each phenomenon in order to give a clue to this diverse world. For this purpose, I prepared a section to explain the elementary optical processes that would at least partly contribute to the structural colors. In addition, I prepared more detailed descriptions as a new section, where I described the detailed derivations of the important formulas, which would help the readers to study the mechanisms. Completing this book, I have noticed that most of

the researches have just commenced in a sense of physics and will offer quite interesting research objects. Thus, this book will be helpful even for physicists to search for new research objects on the sophisticated interactions between light and microstructures, and also on the peculiar self-organization processes undergoing in nature.

Before ending, I would like to express my gratitude to Dr Shinya Yoshioka, who has been extensively performing the experiments and has extended our research field to a variety of animal worlds including butterflies, beetles, and birds. I am also indebted to Naoko Arakawa, Dr Yoshihiko Fujimura, Dr Makoto Kambe, and Eri Nakamura for their direct and indirect supports for producing this book. This book is owed mostly to the researches done by my students, Kenji Kawagoe, Kazuhiko Ikeda, Tsutomu Hamada, Chieko Matsumiya, Naoko Okamoto, and Yasuhiro Fujii, in cooperation with Prof. Akira Saito (Osaka University) and Prof. Takahiko Hariyama (Hamamatsu University School of Medicine). Also, I would like to express my gratitude to Prof. Helen Ghiradella for her sincere support. I owe Dr Akihiro Yoshida (JT Biohistory Research Hall) and Prof. Kuniaki Nagayama (National Institute for Physiological Sciences) for leading me to this fascinating field. I also thank Mr Toshiyuki Suwa of Osaka University Life Sciences Library for kindly helping me in searching the literatures that were difficult to obtain.

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