Kazutami Sakamoto, Robert Lochhead,
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COSMETIC SCIENCE AND TECHNOLOGY: THEORETICAL PRINCIPLES AND APPLICATIONS

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COSMETIC SCIENCE AND TECHNOLOGY: THEORETICAL PRINCIPLES AND APPLICATIONS

Kazutami Sakamoto
Robert Y. Lochhead
Howard I. Maibach
Yuji Yamashita

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Biography

Kazutami Sakamoto, PhD

Kazutami Sakamoto is a former professor of the Faculty of Pharmacy at Chiba Institute of Science and currently a guest professor of the Department of Pure and Applied Chemistry, Faculty of Science and Technology, at Tokyo University of Science. He graduated from the master's program of Applied Chemistry, School of Engineering at Tohoku University in 1971 after finishing an undergraduate program at the same university. He received his PhD from the Faculty of Science at Tohoku University in 1980. In 1971, Dr. Sakamoto joined the Central Research Laboratories of Ajinomoto Co., Inc. as a research chemist and spent most of his professional carrier with the company until 2003. During his time with Ajinomoto, Dr. Sakamoto worked on the development of the Ajinomoto's functional chemical products especially cosmetic ingredients. He also conducted basic research in the area of colloid and interfacial chemistry and skin science. In 2003, he retired from Ajinomoto and joined Shiseido Research Center as a Resident Special Technical Advisor, where he spent three years consulting on the creation and promotion of Shiseido's new R&D projects. He then worked for Seiwa Kasei Co. LTD. as a director of R&D. Along with his industrial career, Dr. Sakamoto has been active in research and education at various universities including Yokohama National University, Shinsyu University, and Tokyo University of Science as an adjunct professor. After retiring from industry in 2008, he has been expanding his academic activities.

Dr. Sakamoto has done extensive research on the physicochemical properties of amino acid—based chiral molecules, especially of their self-assembled conditions, since the late 1970s. His explorations of chiral self-assemblies included micelles, lyotropic liquid crystals, which were pioneering studies in the 1970s. The discovery of lyotropic cholesteric liquid crystal formed by acylamino acid as a chiral surfactant is a good example of this work. His curiosity regarding the structure and functions of chiral assembly led Dr. Sakamoto to create chiral mesoporous silica as a solid matter, which was templated from chiral lyotropic liquid crystal formed by acylamino acid as a soft matter. His study "Self-organization of Amino Acid—Based Chiral Surfactants: Evaluation of Organized Structures and Interactions with Biological System" received an award from the Japan Oil Chemists' Society in 2005. In the past 10 years, he has actively participated in many international conferences as an invited speaker. Dr. Sakamoto was a chairman of the Division of Colloid and Surface Chemistry of the Chemical Society of Japan for 2007—08.

Robert Y. Lochhead, PhD, FRSC

A long-time leader in polymers for cosmetics, Dr. Lochhead is currently Professor and Director Emeritus of Polymer Science at the University of Southern Mississippi. He served as a professor at the School of Polymers and High Performance Materials at the University of Southern Mississippi, and he was director of that school for almost 2 decades. His students have won best annual national/international paper awards for 18 of the 26 years that he spent in academia. Prior to joining academia, the first 25 years of his career were spent in industrial research that ranged from polymer and silicone synthesis to colloid and surface science for cosmetics and personal care products and to the management of the rheology applications segment of a large hydrophilic polymer research group. Dr. Lochhead is the author of more than 100 scientific papers and reviews and a named inventor on 25 patents.

His inventions have enabled new and better technologies that benefit society and the environment. These include:

- Camouflage "makeup" that protects personnel from the ballistic thermal fronts of explosions
- Stimulus-responsive polymer—surfactant systems for personal care and home care (the stimulus-responsive coacervate formation that underpins the mechanism of conditioning shampoos has been named "the Lochhead Effect")

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- The concept of polymeric emulsifiers and the first polymeric emulsifier, which enabled:
  - skin lotions for sensitive skin and sports sunscreens;
  - the now common stimulus-responsive alcohol sanitizing gels;
  - sprays that stay active on plants even when it rains, thereby lowering the frequency of use and reducing runoff of pesticides and herbicides;
  - waterborne water seal coating compositions that essentially eliminate the volatile organic compound emissions of earlier oil-based water seal formulations
- Bioadhesive polymers for the lubrication of mucous membranes and drug delivery
- Compositions for the repair of retinal tears
- Hypochlorite-resistant waterborne rheology modifiers that enabled automatic dishwashing gels
- Novel, ecologically beneficial dispersants for oil spills
- Polymers for textile and carpet printing that essentially replaced kerosene emulsions and the pollution that often went along with the use of these emulsions

Dr. Lochhead has received many awards for his contributions and these include:

- The Maison G. DeNavarre medal from the Society of Cosmetic Chemists
- The Chemical Pioneer Award from the American Institute of Chemists
- The Education Award from the Society of Plastics Engineers

Dr. Lochhead serves on the International Nomenclature of Cosmetic Ingredients committee and he has served twice as the President of the Society of Cosmetic Chemists and President of the International Association of Formulation Chemists.

Howard I. Maibach, MD, PhD

Dr. Howard Maibach is an expert in contact and occupational dermatitis and sees patients at the Environmental Dermatosis Clinic, which is part of the Dermatology Clinic. His specialties are dermatotoxicology, or skin exposure toxicity; allergies and skin disorders; and dermatopharmacology or the study of medications for skin disorders. Dr. Maibach has been on the editorial board of more than 30 scientific journals and is a member of 19 professional societies, including the American Academy of Dermatology, San Francisco Dermatological Society, and the Internal Commission on Occupation Health. He is a professor in the Department of Dermatology at UCSF.

Dr. Maibach has written and lectured extensively on dermatotoxicology (the toxicity to man from skin exposure) and dermatopharmacology (the treatment of skin diseases). His current research programs include defining the chemical-biological faces of irritant dermatitis and the study of percutaneous penetration.

When Dr. Maibach is not in the lab conducting research or in the classroom teaching, he is seeing patients at the Environmental Dermatoses Clinic (of the Dermatology Clinic), mostly providing second opinions on allergic contact dermatitis.

Dr. Maibach has been on the editorial boards of over 30 scientific journals and is a member of 19 professional societies, including the American Academy of Dermatology, San Francisco Dermatological Society, and the International Commission on Occupational Health.

Clinical Specialties.

- Dermatopharmacology
- Allergic Contact Dermatitis

Research Interests.

- Dermatotoxicology
- Dermatopathology
- Percutaneous Penetration

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Yuji Yamashita, PhD

Yuji Yamashita received his MS and BS from Yokohama National University, Japan, and his PhD in natural science from the University of Bayreuth, Germany, in 2005. After several years of research work on thermotropic liquid crystals at Chisso Petrochemical Co., Japan, he began to study dermatology, especially transdermal drug delivery systems, as a postdoc at St. Marianna University, Japan. In October 2011, Dr. Yamashita became an assistant professor at Chiba Institute of Science, teaching and researching cosmetic science; he was promoted to junior associate professor in 2014. His area of expertise is surfactant science such as phase behavior and self-assembly, which is related to formulation technology. His current research topics include establishment of a novel parameter to replace the HLB number, emulsion stability under microgravity, micro-calorimetric study on the structural transitions of self-organized matters, and alpha-gel formulation, of which "establishment of a novel parameter to replace the HLB number" received an award in November 2016 from the Society of Cosmetic Chemists of Japan.

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Foreword

Kazutami Sakamoto
Tokyo University of Science, Chiba, Japan

If you picked up this book, you likely have an interest in cosmetics and you may find yourself struggling to find your specific area of interest in this field, which involves a number of disciplines including natural sciences, technologies, and even social sciences. Cosmetics is an exceptional field where cutting-edge sciences and technologies are quickly applied into innovative products deeply integrated with social, cultural, and traditional lifestyles. This book is structured in four sections to introduce the world of cosmetics by integrating scientific and technological aspects: **General Views of Cosmetic Science and Technology, Fundamental Resources for Cosmetics, Physicochemical Aspects and Formulations, and Physiological and Dermatological Aspects.**

We provide the essence needed to learn what cosmetics are, from both scientific and technological perspectives with interwoven contents in relation to beauty and care. You may be a scientist seeking updated knowledge in cosmetic science and looking for the most advanced and practical information, or perhaps you are a nonscientist looking for reliable and easily accessible introductory information with a robust scientific basis in cosmetics. This book aims to fulfill such needs by providing well-integrated content written by the leading scientists in the field. It provides basic scientific aspects that are integrated into cosmetics in the areas of material development, physicochemical aspects of formulations, and dermatological concerns.

I am grateful to all the contributors that made this book possible by offering their expertise on the basis and application of cosmetic science and technologies. My heart-filled thanks go to the coeditors; without them it would have been impossible to bring this endeavor to fruition. Dr. Howard I. Maibach opened my eyes not only to the world of science but also connected me with a new network of people. When I arrived in San Francisco in late August 1983, I had no practical communication skills in English and he so kindly offered to help me in every aspect of living and working in the United States. Since then, Howard has always been my mentor. Dr. Robert Y. Lochhead, with whom I became acquainted through a colleague at Ajinomoto USA Inc., kindly accepted a scientist from Ajinomoto to study at his lab in the mid-1990s. Since then we have become close friends. Bob has been kind enough to visit and encourage my students at Chiba Institute of Science (CIS) in Japan, after I opened my own lab for cosmetic science in 2012. My relationship with Dr. Yuji Yamashita started at the beginning of the 21st century. I was a guest professor at Prof. Hironobu Kunieda's lab at the time and Yuji was a graduate student, and I have supervised for his master's degree thesis. When I started my new career at CIS in 2010, Yuji was a postdoctoral scientist at the St. Marianna University School of Medicine in Japan after finishing his PhD at Bayreuth University in Germany under Professor Heinz Hoffman and had several years of experience in industry. I invited Yuji to join me to establish our lab, and Yuji now leads the lab after my retirement from CIS.

I feel life is always filled with unexpected encounters with people and opportunities, which grow into an interwoven network. In this sense, this book is a great outcome of my long journey. I hope readers will enjoy this book and find an opportunity to explore the world of cosmetic science and technology, and go further with their own journeys.

My first thanks goes to Emeritus Professor Hiroyuki Ohshima of Tokyo University of Science (TUS) and Dr. Kostas Marinakis of Elsevier B.V. Registered Office who brought this project to me. One day in early 2013, Prof. Ohshima found me on the platform of Kashiwa Station, which many people use to commute to TUS. Since we were both members of the Division of Colloid and Surface Chemistry at Chemical Society Japan, he knew my background of working in industry and academia. He proposed this project when it was still just a concept brought from Kostas. At the meeting with Kostas in New Orleans at the Spring ACS meeting in April 2013, Kostas inspired me to reveal the scientific treasures hidden deep inside the cosmetic companies and the secret resources of cosmetic products that bring dreams to consumers. My journey started with these two encounters. Howard and Bob guided me with their expertise on how to explore science and technology even further, and with Yuji's patient support our

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journey has finally reached its goal. We hope this book opens doors to our readers and helps them start their own expeditions.

I am also indebted to Sarah J. Watson, editorial manager of Physical Science and Maria J. Bernard, project manager of Science and Technology Books at Elsevier for their editorial assistance and patience, and to my son Izumi Sakamoto for his contribution of translating many chapters originally written in Japanese to English while preserving the cultural flavors to the universal language just as cosmetics itself has a nature of commonality and demographic diversity.

In closing, I offer my profound thanks…

To my teachers, many friends who have enriched my life in more ways I can express.

To my family who stood by me and supported me in the many years I lived in the United States and after resettling in Japan. I give special thanks to my wife Mariko for all the love and dedication to our family.

Kazutami Sakamoto
November 28, 2016

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Preface

During the past quarter of a century, the reach of cosmetic companies has become global and our understanding of the underlying scientific principles has sharpened and expanded. We now have a better understanding of structure—property relations down to ingredient molecular levels and physical interactions; our understanding of the biochemistry, biology, and morphology of skin and hair has advanced significantly, even as formulated compositions have become increasingly constrained by regulation. Cosmetic science is now entering an era of increased ecological awareness that will probably persist for the next quarter of a century as more of the world's burgeoning population becomes able to enjoy the benefits of personal care products. Nevertheless, despite worldwide domination by a few multinational corporations, there are still regional variations that result from cultural preferences and regulatory differences, and these offer new challenges to the formulators of today and tomorrow.

At this juncture, there is a need to review the state of the art, to mentor the next generation of cosmetic scientists, and to establish a starting point for the forthcoming era of cosmetic science. The purpose of this book is to address that need. It constitutes a comprehensive review, with contributions from some of the world's leading cosmetic scientists. The need to condense our knowledge into a document was brought home to me poignantly when I sought guidance on a technical point from a colleague, only to find out that he had died 2 weeks earlier and his advice was silenced forever.

I am grateful to Dr. Kazu Sakamoto for inviting me to participate as a co-editor and for taking the lead in this venture. I am also thankful to Dr. Yuji Yamashita for his dedicated efforts in uploading the chapters and to Dr. Howard Maibach for lending his experience and skill to the planning and implementation of the book.

During my career in cosmetic science, I have had the privilege of being mentored by many excellent scientists, too many to mention individually in this short preface, and I thank them for molding me into the professional that I have become. In particular, I wish to thank my wife, Margaret, for her encouragement and for her contributions to figures and equations in my publications.

Reader, I hope that this book will enlighten you, and I encourage you to drive our understanding of cosmetic science to a broader and deeper level.

Robert Y. Lochhead
August 2, 2016

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outcome of a technology in which crystals of barium sulfate that function as reflector boards are formed upright on a red pearl pigment. This is a unique powder that was born inspired by a reflector board used for photographing and filming. Foundations formulated with this powder could improve sagging face line, making the applicant look a lot younger than her actual age.

On the other hand, the development of a powder that prevents skin roughness began from finding out that an enzyme called "urokinase" exists on the skin surface that produces "plasmin," an enzyme that is known to be responsible for roughening skin. Through screening for a powder that can effectively counteract urokinase, zinc oxide was found to inhibit the activities of urokinase whilst talc and silica can adsorb urokinase. A foundation formulation containing a composite powder of talc and zinc oxide, and zinc oxide coated with silica, was prepared to investigate its skin care effect (Paper no. 47:2002, Table 2.1). The breakthrough was brought about by focusing on the skin care effect through the removal of the contributor to skin roughness, rather than conventional composite powders that were designed merely to arm them with optical functionalities.

2.4.3.3 Innovative Functional Formulations That Created New Values

So far we have gone through award-winning papers on skin biology, emulsification technologies, and functional powders for makeup cosmetics. In this section, we will touch on award-winning papers related to development of formulations with new functions from new perspectives. Development of cosmetics in recent years is being strongly driven toward what the consumers want, and innovative attempts to fulfill such demands have received IFSCC Awards. The common features shared here are that they all commence by investigating what the current issues are, then seek solutions for such issues, and finally incorporate the solutions into workable formulations.

2.4.3.3.1 A Deodorant That Works in an Instant

In the 1980s, the main mechanisms through which deodorant products intended to combat body odors worked were the usage of antiperspirants that prevent perspiration from the sweat glands, antimicrobials that inhibit the activities of residential bacteria from degrading odorless sweat and sebum-derived substances into odorous compounds, and masking offensive body odors using citrus and floral fragrances. However, their efficacy was insufficient to live up to the expectations of the consumers. The report by F. Kanda et al. in which they developed an innovative deodorizer that not only prevents body odors as did conventional products but could also instantly quench body odors once formed, won them an IFSCC Award in 1988 (Paper no. 24:1988, Table 2.1).

After pinpointing "short chain fatty acids" as major contributors to offensive body odors, the authors studied further to look into why some people smelled more intensely than others with only faint odors.[20] They eventually ascertained that short chain fatty acids were also present in people with faint odors, but as odorless metallic salts and not as the free odorous form that was abundantly found in smelly people. This led the authors to believe that the malodors of free short chain fatty acids could be quenched by converting them into odorless metallic salts and found out that zinc oxide could effectively pursue this objective. However, zinc oxide can easily aggregate within a formulation and would cause aerosol sprays to clog. To overcome this issue, a new hybrid powder (Fig. 2.9) was developed in which a spherical synthetic resin core powder is evenly coated with a monolayer of fine zinc oxide particles. This gave birth to a consumer-friendly formulation with exceptionally high deodorizing capabilities.

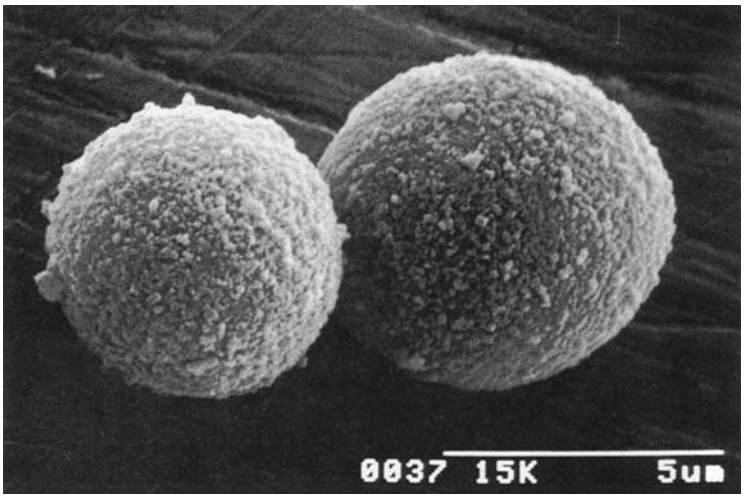

FIGURE 2.9 Electron micrograph of "hybrid powder."

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Zinc oxide is also known to have skin care effects. For example, zinc oxide is reported to have convergence effects that tighten the skin to make pores less visible,[40] antibacterial effects that kill skin irritation and infection-causing *Staphylococcus aureus/Pseudomonas aeruginosa*,[41] and antiacne effects.[42] Furthermore, zinc oxide selectively adsorbs free fatty acids, and this characteristic has been applied to products such as foundations through development of techniques to prevent makeup smears by adding zinc oxide to cosmetics in order to improve the stability of the cosmetic layer on the skin.[43]

14.2.1.3.3 Calcium Carbonate

Calcium carbonate, $CaCO_3$, is a white to light gray powder found in shells, corals, eggshells, and limestone. Calcium carbonate is usually porous[44] and by filling these pores with medical agents or aromatic agents, they are formulated in pharmaceutical drugs and cosmetics.[45,46] When used for foundation or face powders, they can absorb sebum and increase the sustainability of the cosmetic effects, providing a clear finish.

14.2.1.4 Pearlescent Pigments

The clear and soft shine of pearls has allured us throughout history. Pearlescent pigments are artificial replications of this naturally borne mechanism. The unique gloss of natural pearls is thought to be made by light interference of the parallel layers of multiple overlapping calcium carbonate crystal layers and protein layers, and the light interference of the scattering light of crystals in the crystal layers[47] (Fig. 14.3). Scale-like particles with planar or needle-shaped structures and a relatively high refractive index have been used to replicate this pearly gloss in cosmetics.[8] Furthermore, a method was developed to replicate the colors with interference light by coating the surface of planar mica with titanium oxide or iron oxide, and has been applied to cosmetics.[48] Especially in the 1980s, technology to control the thickness of the coating was established and made it possible to formulate various colors such as red, blue, yellow, and green, and this was applied not only to makeup cosmetics but also for foundation to make the finish more natural.[49,50]

14.2.2 Organic Pigments

14.2.2.1 Extender Pigments

14.2.2.1.1 Polymer Resin

Methyl methacrylate crosspolymers, silicone resin, nylons, urethane resin, and various other polymer resins have been used to preserve the shape of formulations and improve the application touch or to control the gloss as extender pigments. Most polymer resins are spherical particles sized from several hundred nm to tens of μm, but nylon can be supplied in various shapes, ranging from spherical to fibers. Spherical polymers scatter light and can provide a soft focus effect where the pores are less visible,[51] and fiber-shaped polymers are added to mascaras to make the eyebrows thicker and longer, and are even used for base makeup to create a younger-looking skin texture.[52]

14.2.2.1.2 Surfactants and Metal Salt

Crystals of surfactant metal salts such as magnesium myristate, zinc myristate, and calcium lauroyl taurate, or surfactants such as lauroyl lysine, are sometimes used as extender pigments or surface treatment agents for makeup cosmetics. These crystals are white and smooth powders, and they have high hydrophobic properties as well as

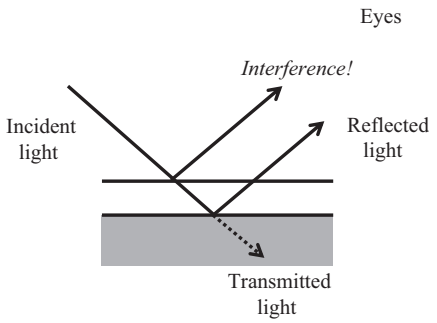

FIGURE 14.3 The coloring mechanism of interference pearls.

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