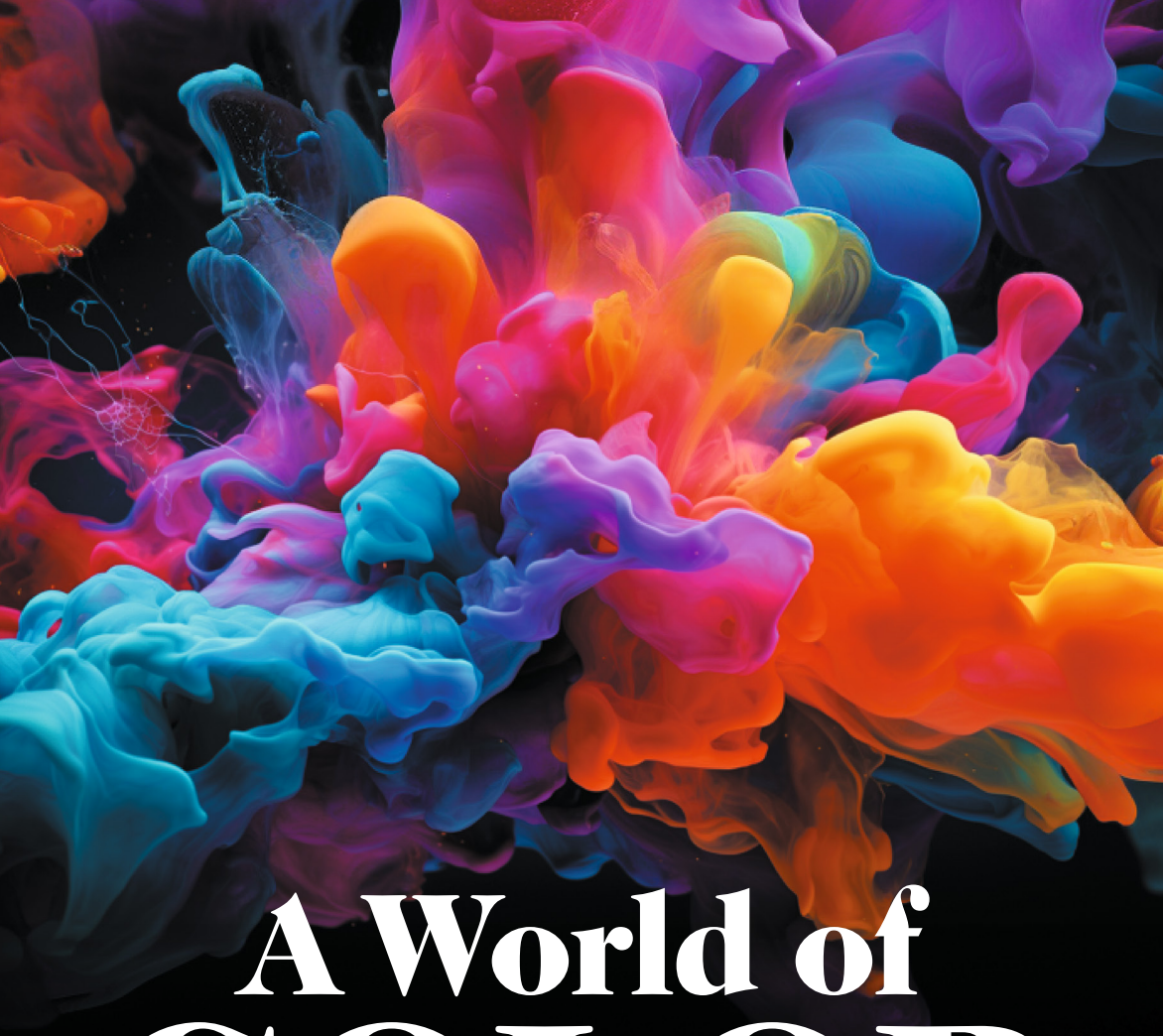

A World of COLOR

The Science of Color in Everyday Life

David Cann

Springer

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David Cann
Oregon State University
Corvallis, OR, USA

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To my family. Without their love, support, and inspiration this would not be possible.

Preface

This book came about from a course I've taught for the Honors College at Oregon State University since 2020. The course is taught in a "colloquium" format with a goal of guiding students through a subject that lets you see the world from a different perspective through lectures, reading material, and lots of discussion. Most of the colloquium courses taught by my colleagues are focused on topics in the liberal arts and humanities, but I think color is a unique subject for a course of this type. Color is a critical aspect of our everyday lives, both subjectively and emotionally. As the book describes, the origins of color are often linked to invisible processes that yield insights about the universe around us. With a little knowledge about the physical and chemical mechanisms behind the colors we observe, we see the world a little differently. It is my hope that this book serves this purpose for the reader.

The subject of color is probably one of the broadest topics in science in that it spans multiple disciplines from physics to chemistry to geology to biology to engineering and even human anatomy. As a material scientist, my 30+ years of research and teaching experience provides a useful frame of reference for writing this book. While a lot of the topics are outside my expertise, the overarching philosophy of materials science is focused on structure-property relationships. That is, how does the particular arrangement of atoms and molecules in material influence the properties were observe. This vantage point is extremely useful in discussing the many color mechanisms in this book. There is a nearly infinite amount of detail for each color mechanism, but the most interesting part is merely the linkage between the color we

observe and atomic or microscopic structure of the material. The goal is not to be a textbook on color mechanisms, but a field guide for the reader that explains what goes on behind the scenes in our colorful world.

Since I've spent my entire life as an academic, I often find it hard to gloss over details because often times the details matter. However, in writing a science book aimed at the general public, inserting countless caveats and qualifying statements into the narrative would result in boring the reader beyond all hope. Thus, in this book I will aim to stay true to the goal of explaining the fundamental scientific concepts without disrupting the flow. For that I am indebted to my editor and many colleagues that have helped me put this together.

I am also indebted to Dr. Kurt Nassau who authored the book *The Physics and Chemistry of Color: The Fifteen Causes of Color*. This is an incredibly unique book that was one of the primary motivations for this book. From his bibliography from the Gemological Institute of America, Dr. Nassau was a research chemist and minerologist at AT&T Bell Labs for 30 years, retiring as Distinguished Research Scientist in 1989. His book is an impressive encyclopedia of color that discusses the origins of color in great technical depth. It is a hidden gem that many of my material scientist colleagues hold in very high regard. After reading my book, his book is an excellent reference for greater level of detail into the physics, chemistry, and biology.

Corvallis, USA David Cann

Acknowledgements There are so many people to acknowledge I don't know where to start! First off, I have to acknowledge someone I've never met. Kurt Nassau's book *The Physics and Chemistry of Color* is truly the inspiration for this book. I found this gem early in my academic career and it has served as an invaluable resource in helping me understand color mechanisms in materials. The chapters on color mechanisms in minerals was incredibly useful for undergraduate and graduate materials science classes, and the entire book effectively served as a template for this book. Nassau's book is truly an impressive achievement in that it covers every conceivable color mechanism in an amazing level of detail. You will also note that his book is listed as a reference for most of the chapters in this book because it is a great place for the reader to go if they want more detailed information on the topics in this book.

I am also indebted to my wonderful colleagues at Oregon State University that served as guest speakers for my Honors colloquium class *A World of Color*. Their knowledge and passion helped broaden my appreciation for color. Dr. Christopher Marshall shared his infectious enthusiasm for the colorful world of insects with my class. I loved his captivating stories of collecting bugs in the Amazon rainforest and learning about the impressive abilities of the humble beetle. Anna Fidler showed us around her art studio and helped us understand the nature of color through the eyes of an artist. Dr. Vince Remcho showed my class how color can be used for chemical analysis using your smart phone. Marianne Dickson's joy was palpable when she demonstrated how to color fabrics with natural dyes from flowers, barks, and even insects. Dr. Luanne Rolly explained the wonders of ink jet printing—which is truly one of the most amazing engineering achievements of our age. Last, but not least, Dr. Brian Bay helped us understand what happens behind the lens when images are rendered on our computer screens and in our brains. I am incredibly thankful to have such gifted and generous colleagues at Oregon State University.

I am fortunate to have great friends that have supported me along the way. First and foremost, my friend and colleague Dr. Bill Warnes helped proof the entire manuscript (though don't blame him for any errors that crept into the final text!). His attention to detail and timely feedback helped make this book the best it can be. Thanks also go to my old friend David Bartlett for his help with reading one of the final drafts. My friend and fellow editor Dr. Grant Norton provided sage advice to me on how to get started with writing a book like this. I can highly recommend his excellent books *A History of Modern Materials* and *Ten Materials That Shaped Our World*. I would also like

to thank Dr. Katie Burke who helped in the early stages of writing. Her guidance and input really helped me with style and storytelling. I would also like to thank Bruce Mulholland for his help compiling important data on fluorescence which appears in the book. Finally, but most importantly, I am truly grateful to my wife Ilene Cann. Her sharp eye and "right-brain" viewpoint helped me rewrite some of the critical sections of text to be more meaningful to a broader range of readers.

To all, thank you from the bottom of my heart.

Competing Interests The author has no competing interests to declare that are relevant to the content of this manuscript.

Contents

About the Author

David Cann grew up in the suburbs of Washington, D.C., but moved to Oregon in 2005 to join Oregon State University as Professor of Materials Science. He has spent more than 30 years as a researcher working on ceramic materials for electronic applications. He taught a colloquium course on the physics and chemistry of color for OSU's Honors College which catalyzed his interest in color. More importantly, color is everywhere in his life outside of work. As an avid hiker, his life is filled with colorful wildflowers, vibrant landscapes, minerals, and wildlife in the Coastal and Cascade mountain ranges near his home. His curiosity fed the desire to learn more about the science behind the colorful outdoor universe.

The inspiration for this book came about from reading Carl Sagan's book *The Demon-haunted World: Science as a Candle in the Dark*. In the book, Sagan focuses on the primal feeling of "awe" people have when contemplating science and nature. He advocates the point of view that science education is most impactful when it connects to that sense of awe. Color naturally fits into this paradigm. We see it, we experience it, and we even feel it. The purpose of this book is to magnify the sense of wonder by connecting color to the natural world through the exploration of scientific principles.

The author lives in Oregon with his wife, two sons, a dog, and a mischievous cat. When not working, writing, or hiking, he enjoys spending time with the family, cooking, sports, and board games.

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The Nature of Color

Color is beauty. Color is emotion. Color is life.

Every facet of the world we experience is enriched by color. When we first open our eyes at dawn, we are met with warm hues that gently arouse our senses. Throughout the day, as we make our way through the world color guides us, informs us, warns us, and stimulates our senses. The photoreceptors in our eyes are well matched to the spectral output of our sun and their functionality has evolved over the years to help us survive. Color tells us when to stop at an intersection, when something is safe to eat, and whether we should go see a doctor about that mole on my arm. Color might give us a hint about which section you should sit in at a contentious sporting event, and color can tell us whether a gathering of people is a wedding or a funeral. Beyond the physical appearance of color, its primary importance in our lives is reflected in many aspects of the human experience. We describe political processes using color, with green parties aligned with environmental movements around the world, red is historically associated with the international socialism movement, and recently the United States has been subdivided into blue and red states. Even our emotional states are described by color, with angry reds, cowardly yellows, envious greens, and moody blues. These emotions can be intertwined with the colors of our physical environment. Our moods are linked to the colors in our homes, with warm colors like beige and cream, and cool colors like teal and grey. Color is obviously central to many expressions of art, from the bold primary colors of Mondrian, to Picasso's blue period, to Seurat's mixing of colors through the pointillism technique. Colors are often expressed in music, from Dylan's *Tangled Up in Blue*, Prince's *Purple Rain*, REM's *Orange Crush,* and Coldplay's *Yellow*. Of

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