Preface

This textbook has its roots in a course that was first given by Gary Goldstein and me at Tufts University in 1971. Both of us are theoretical physicists, with Gary focusing on the study of elementary particles and me focusing on condensed matter physics, which is the study of the fundamental behavior of various types of matter – superconductors, magnets, fluids, among many others. However, in addition, we both have a great love and appreciation for the arts. This love is fortunately also manifested in our involvement therein: Gary has been seriously devoted to oil painting. I have played the violin since I was seven and played in many community orchestras. I am also the founder and director of a chorus. Finally, I am fortunate to have a brother, Perry Gunther, who is a sculptor and my inspiration and mentor in the fine arts.

It is common to have a course on either the Physics of Music or the Physics of Color. Numerous textbooks exist, many of which are outstanding. Why did we choose to develop a course on both music and color? There are a number of reasons:

1. The basic underlying physical principles of the two subjects overlap greatly because both music and color are manifestations of wave phenomena. In particular, commonalities exist with respect to the production, transmission, and detection of sound and light. Our decision to include both music and color was partly due to the fact that some wave phenomena are relatively easy to demonstrate for sound but not for light; they are experienced in every day life. Examples include diffraction and the Doppler effect. Thus, the study of sound helps us understand light. On the other hand, there are some wave phenomena – common to both sound and light – that are more easily observed for light. An example is refraction, wherein a beam of light is traveling through air and is incident upon a surface of glass. Refraction causes the beam to bend upon passing into the glass. Refraction is the basis for the operation of eyeglasses. And finally, there are wave phenomena that are easily observable for both sound and light. Interference is an example.

Two stereo loudspeakers emitting a sound at the same single frequency produce dead (silent) regions within a room as a result of the interference between the two sound waves produced by the two loudspeakers; the colors observed on the CDs of the photo in the frontispiece are a result of the interference of light reflected from the grooves within the CDs.

2. The production of music and color involves physical systems, whose behavior depends upon a common set of physical principles. They include vibrating mechanical systems (such as the strings of the violin or the drum, vibrating columns of air in wind instruments and the organ), electromagnetic waves such as light, the rods and cones of the eye, and the atom. All manifest the existence of **modes** and the phenomena of excitation, resonance, energy storage and transfer, and attenuation.

   CDs "produce" sound through a series of processes that involve many distinct physical phenomena. First, the CD modulates a laser beam that excites an electronic device into producing an electrical signal. The laser light itself is a manifestation of electric and magnetic fields. The electrical signal is used to cause the cone of a loudspeaker to vibrate and produce the motion in air that is none other than the sound wave that we hear.
3. The course that led to the writing of this book offers us the opportunity to study a major fraction of the basic principles of physics, with an added important feature: Traditionally, introductory physics courses are organized so that basic principles are introduced first and are then applied wherever possible. This course, on the other hand, is based on a motivational approach: Because of the ease of observing most phenomena that is afforded by including both light and sound, we are able to introduce the vast majority of topics using class demonstrations.

   We challenge ourselves by calling for a physical basis for what we observe. We turn to basic principles as a means of understanding the phenomena. A study of both subjects involves pretty nearly the entire gamut of the fundamental laws of classical as well as modern physics. (The main excluded areas are nuclear and particle physics and relativity.)

Ultimately, our approach helps us appreciate a central cornerstone of physics – to uncover a minimal set of concepts and laws that is adequate to describe and account for all physical observations. Simplification is the motto. We learn to appreciate how it is that because the laws of physics weave an intricate, vast web among physical phenomena, physics (and science generally) has attained its stature of reflecting what some people refer to as "truth" and, much more significantly, of having an extraordinarily high level of dependability.

The prerequisites for the associated course are elementary algebra and a familiarity with the trigonometric functions. The only material in the textbook that requires a higher level of mathematics is the appendix on the Transformation of Color Matching Functions (Appendix I) from one set of primaries to another – the analysis requires a good understanding of matrices. I have never included this appendix in my course; it is available for those who might be interested in it. The level of the textbook is such as to produce questions as to whether a student without inclinations to major in the sciences can handle the material. It has been my experience in teaching the associated course at Tufts University for over 35 years, that very few such students have failed to do well in the course. In the Fall, 2009 semester, in particular, the 15 students who took the course were all majoring in the Arts, Humanities, or Social Sciences or as yet had not declared a major. The average score on the Final Exam was a respectable 73%, with a range from 61% to 94%.

When I have taught the course using this textbook, I have often had to omit the section on Polarized Light for want of time. Sections that can be skipped without loss of continuity for the remaining material are marked with a double asterisk (**).

Note on problems and questions: Whether you are reading this book in connection with a course you are taking or reading it on your own, I strongly urge you to take the questions and problems in the book very seriously. To test your understanding and to measure your level of understanding, you have to do problems. In all my more than 50 years of studying physics, I have never truly appreciated a new subject without doing problems.

There are many fine books already available that cover either the physics of sound and music or the physics of light and color. Some of these books go into great depth about a number of the subjects, way beyond the depth of this book. For example, you will not find details on the complex behavior of musical instruments in this book. The book by Arthur Benade, listed in the Appendix of references D, is a great resource on this subject, even though it is quite dated. And, you will not find in-depth coverage of the incredibly rich range of light and color phenomena that is treated in the wonderful book by Williamson and Cummins. Their section on oil paint is outstanding. Instead, you should look on this book as a resource for gaining an in-depth understanding of the relevant concepts and learning to make simple calculations that will help you test hypotheses for understanding phenomena that are not covered in this book. You will be able to read other books and articles on the web empowered with an understanding that will help you appreciate the content. One of the problems raging today (2011) is the proliferation of information. Ah yes, you can look up on the Web any topic in this book. Unfortunately, a huge fraction of the information is incorrect or unreliable.[1] How can you judge what you read? The

[1]Recently, the SHARP Corporation announced that it was going to make available a color monitor and TV that has **four primary colors** among the color pixels, in contrast to the three primaries currently used. As a result, it claimed that the number of colors available would approach one trillion. (See their website: http://www.sharpusa.com/AboutSharp/NewsAndEvents/PressReleases/2010/January/2010_01_06_Booth_Overview.aspx) Yet you will learn in Chap. 14 that human vision can differentiate only about ten million colors. Therefore, even if the Sharp monitor were able to produce one trillion colors, viewers would not be able to benefit from this great technology. We can still ask what can possibly be the gain in adding a yellow primary? Is their chosen color yellow for the fourth primary the best one to choose to improve our color vision? See Chap. 14 for information on this question. Websites abound dealing with the significance of Sharp's new technology; this book will help you analyze and judge what you read.

only solution is for you to accumulate knowledge and understanding of the basics and to criticize what you read.[2]

Acknowledgements First and foremost I am indebted to Gary Goldstein, who was a co-developer of the original course on The Physics of Music and Color. Gary's contributions in teaching a number of the subjects in a clear way were invaluable. Most noteworthy were his ideas for teaching color theory. I am grateful to my daughter, Rachel Gunther, for producing the first word-processed draft of the book. I am deeply indebted to Stephan Richter, one of my graduate students, who was a driving force and indefatigable in producing a Latex copy of the book, worked over numerous figures, and is responsible for the layout of the book. I had a number of teaching assistants over the years who made very valuable contributions in teaching the course, most notably Stephan Richter and Rebecca Batorsky. Both Stephan and Rebecca are gifted teachers and frequently shared productive advice for me. My long time friend and violin teacher, Wolfgang Schocken, was a well-known teacher of the violin. He was also extremely knowledgeable about the numerical issues involved in intonation, which he shared with me. In spite of my familiarity with resonances and overtones of a vibrating string, it was he who taught me to listen carefully to the resonant vibration of unbowed strings to vastly improve my intonation. My son, Avi Gunther, who got his Bachelor's degree from the Berklee College of Music in Boston with a major in Music Production and Engineering, was often extremely valuable in advising me on many aspects of music and on sound production.

I benefitted greatly from two readers of this book: The first reader was my personal opthalmologist, Dr. Paul Vinger, who pointed out numerous typos and provided me with questions that he suggested be addressed in the book. My second reader was a student of mine, Bryce Meyer, who did an incredibly dedicated job reading carefully through the book – finding typos and making countless suggestions for improving the clarity of various passages in the text. Bryce also helped me with some figures.

Many individuals have helped me in one way or another toward the writing of this book. I list the following with apologies those who should be here but are omitted: Paavo Alku, Anandajoti Bhikku, Bruce Boghosian, Andrew Bregman, Andrew Clarke, David Copenhagen, Tom Cornsweet, Russ Dewey, Marcia Evans, Oliver Knill, Paul Lehrman, Ken Lang, Jay Neitz, Donna Nicol, Ken Olum, Charles Poynton, Jeffrey Rabin, Brian Roberts, Judith Ross, Eberhard Sengpiel, George Smith, and Raymond Soneira. This book would not have been published were it not for the strong support and help of my editors, Christopher Coughlin and HoYing

[2]What applies to information on science applies to all subjects. If you are given a multitude of conflicting **expert** opinions on a subject, you will tend to choose one expert who is closest to your point of view or you will want to throw all the sources out the window with the conclusion that reliable information not only cannot be found but has no meaning. The fascinating book by Neil Postman – *Amusing Ourselves to Death* [Penguin Books, N.Y, 1986] – discusses some related problems connected with this proliferation of information.

Fan. I want to pay special attention to Kaća Bradonjić, who produced tens of figures with great finesse, especially those in Chap. 5 that are based on my crude hand drawings.

This book has been a work in progress for more than 35 years. It has had many drafts. I need to share with you my deep appreciation for my loving wife, Joelle, for supporting me in this effort. Whenever I needed encouragement to sustain my spirits and energy, Joelle was there for me.

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