Physics Behind Music

This engaging undergraduate text uses the performance, recording, and enjoyment of music to present basic principles of physics. The narrative lays out specific results from physics, as well as some of the methodology, thought processes, and “interconnectedness” of physics concepts, results, and ideas. Short chapters start with basic definitions and everyday observations and ultimately work through standard topics, including vibrations, waves, acoustics, and electronics applications. Each chapter includes problems, some of which are suited for longer-term projects, and suggestions for extra reading that guide students toward a deeper understanding of the physics behind music applications. To aid teaching, additional review questions, audio and video clips, and suggestions for class activities are provided online for instructors.

Bryan H. Suits has been a professor in the Department of Physics at Michigan Technological University (MTU) since 1985. An award-winning teacher, he has taught physics courses at all levels. An accomplished amateur musician with decades of experience, the author has combined his enthusiasm for physics with that for music to find ways to improve physics literacy among nonphysicists.
“This textbook is written with a palpable passion for physics, music, and communicating science to others.

Clearly a result of years of teaching the topic, it covers the basics in both physics and music comprehensively. While not requiring prior knowledge, the physics principles covered here are advanced, from the concepts of superposition and normal vibrational modes to waves and uncertainty principle. All are considered with a good depth despite using barely any mathematics.

What makes this stand out from other physics texts is the deep connection with music both in terms of using physics to explain principles underpinning music, but also in terms of capturing the philosophy of both fields. The book does not shy away from the human perception side of the story, which is critical in music and rarely, if ever, considered in physics.

I believe it will be valuable for teaching to interdisciplinary audiences or when introducing more advanced physics topics to A-level students. I also believe music students would benefit from looking at least at the parts describing physical aspects of various musical instruments and hall acoustics.

I particularly like that the text is written as a textbook with exercises, and I hope it will encourage more universities to teach physics in an interdisciplinary context and in relation to music. Once it is published, I will use it in the reading list for the Science of Music module that I teach.”

Oksana Trushkevych, University of Warwick

“I highly recommend this book. The text is readable, and suitable for a broad range of student levels. The end-of-chapter problems connect well with the chapter content, and provide a reasonable balance of beginning and advanced questions. The progression of topics is logical, the range is wide, and the content intriguing.”

Ananda Shastri, Minnesota State University Moorhead
Physics Behind Music
An Introduction

Bryan H. Suits
Michigan Technological University
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Preface

This book is about the many areas of basic physics, and the application and practice of physics, behind the production, performance, recording, and enjoyment of music. The emphasis and the organization follow from the development of those basic physics topics from a physicist’s point of view. The expectation here is that the reader has a math background up to but not including calculus. That includes some algebra, plane geometry, and familiarity with the use of simple graphs and functions. Those who may have learned those skills at one time but have not used them in a while must be willing to relearn them.

My parents were both strong in the physical sciences as well as active amateur musicians. It is not surprising that some of that rubbed off on me. I started to get serious about making the connection between the two over 20 years ago, and I was surprised to see how much information was available. Around the same time, I gained an increased interest in improving physics literacy, especially among nonphysicists. While there were already textbooks available that were very nontechnical and often math-less, as well as highly technical references works, there did not seem to be much in the middle. I felt it appropriate to develop some teaching materials that do require some math skills but are not overly technical, certainly less than might be expected of a graduate student or specialist.

The materials in this book were first developed to meet the needs of a short summer course, to develop some related web pages on the subject, and then for a semester-long course. The audience for that semester-long course is students studying technical disciplines, although not usually in physics. During the development of this book, I found myself asking, in the context of the application to music, “What would I, a physicist, like a well-educated nonphysicist to know about physics and the practice of physics?” The answer includes some specific results from physics but also some of the methodology; some of the thought processes; and some of the “interconnectedness” of physics concepts, results, and ideas. The specifics are, admittedly, my personal choices, and to be sure, not all physicists will agree with those choices or the order of their presentation.

I have tried to develop the book with a variety of readers in mind. That includes those who use it as a primary or secondary text for a course on the subject, as well as individuals who would like to learn more about the subject on their own. It is recognized that this is a wide audience that shares an enthusiasm for both science and music but, individually, may have a wide range of experience, expertise, motivation, and other interests. To keep the material available to as wide an
audience as possible, I have assumed that the reader, although technically inclined, has no particular musical skills and little, if any, prior experience with physics as a discipline, with apologies to those who have either or both.

The sequence of topics in the book is an attempt to initially define and introduce the subject using material already known more than 2,000 years ago, long before the development of the formal mathematics of Descartes, Leibniz, Fourier, and many others, and before the advances in physics by Galileo, Newton, and Einstein, to name a few. It should be possible to at least start the discussion using the simpler tools and understandings from long ago. This is not to say mathematics is avoided. Mathematics is the language of physics, and ultimately, physics results are normally expressed in that form. The level of mathematics is then pushed a bit in some of the later chapters. A review of some relevant mathematical material is included in the appendices for the convenience of those who need some review.

To make it easier to adapt the material for a variety of circumstances, it is presented using a large number of shorter chapters. If a particular topic is not of interest, it can be skipped. Some of the more technical material that is, perhaps, a bit less musical can be omitted if desired and is noted as optional.

The 20 chapters, each of which can be covered in one or two class periods, represent material that can be spread over a somewhat intense semester-long course. The first group of four chapters discusses musical notes, frequency and pitch, chords, and ultimately, the description in terms of spectra. The next five chapters look at oscillating mechanical systems, starting with the harmonic oscillator, vibrating strings generalized to plates and chimes, and then simple traveling waves in one dimension and the uncertainty principle. A brief discussion of the very difficult, but essential and often omitted, topic of nonlinear physics follows. The next six chapters develop sound and acoustics, starting from atoms and molecules and ultimately leading to the wave behavior of sound in three dimensions. The final four chapters look at electricity, magnetism, and electronics in musically relevant situations. In each case, the emphasis is on the basic physics of the situation, including, where possible, how that same physics may show up in other situations. The discussion generally does not delve into, for example, the details (i.e., the engineering) of any particular musical instrument. There are other texts specifically about the physics of musical instruments that can be consulted for such details.

There are a few themes that span multiple chapters. Those include exponentials and logs, beats in various contexts, the interplay of restoring forces and inertia for mechanical oscillations and waves, and the idea that the physics seen here is also applicable in many other circumstances.

Suggestions for extra reading are included at the end of each chapter. These include references specifically mentioned in the text, as well as some others that simply may be interesting for additional exploration. An exception is the very last
chapter, where the suggested resources also include readily available audiovisual materials. These lists are not intended to constitute a complete bibliography.

A set of problems can be found at the end of each chapter. Some of these are intended to be straightforward and follow the examples given in the chapter text. When solved in the examples, where possible, the solution is presented using an approach based on understanding the physics rather than “finding a formula and plugging in values.” That latter approach is a strategy often used by beginning students and should be strongly discouraged. The later, more difficult end-of-chapter problems may work best with small-group discussions (e.g., in class), and some may require additional investigation beyond what is in this text. Some might even be best suited for longer-term projects.

It would be expected that many demonstrations, hands-on activities, and possibly projects will also be carried out in class. The details will depend on what is available and of interest to the instructor, and suggestions for each chapter are available as an ancillary resource accompanying this book. Instructors are especially encouraged to use real equipment, rather than simulations, whenever possible, at least to get started. While it is tempting to use simulations, and many are readily available, they are not real, and in practice, not all students understand what simulations are showing. If real apparatus is not available live, then there are likely many recorded versions that can be used.

There are supplementary chapter review questions, in a multiple-choice format, that are available to instructors from the publisher’s website (www.cambridge.org/suits). These questions are supplied in a format that can be easily imported into most learning management systems (LMSs). The questions test for knowledge of basic definitions and concepts from the chapter and are intended as an important complement to the end-of-chapter problems. Some additional ancillary materials are also available at that site, including audio and video files that may help in the classroom, as well as some supplemental material for selected topics. Instructors are especially encouraged to visit that site.

As an added feature, figures identified in the figure caption with a ‘★’ are available in an alternate, animated format that can be found in the e-book version and at the publisher’s website (www.cambridge.org/suits).