Chapter 1
Introduction

Abstract Initially, the introductory chapter deals with different ways people comprehend physics. It might provide a better understanding of the structure of the book and choices of the topics covered. It continues with a description and discussion on how the introduction of computers and numerical methods has influenced the way physicists work and think during the last few decades. It is indicated that the development of physics is multifaceted and built on close contact with physical phenomena, development of concepts, mathematical formalism and computer modelling. The chapter is very short and may be worth reading!

1.1 The Multifaceted Physics

Phenomena associated with oscillations and waves encompass some of the most beautiful things we can experience in physics. Imagine a world without light and sound, and then you will appreciate how fundamental oscillations and waves are for our lives, for our civilization! Oscillations and waves have therefore been a central part of any physics curriculum, but there is no uniform way of presenting this material.

"*Mathematics is the language of physics*" is a claim made by many. To some extent, I agree with them. Physical laws are formulated as mathematical equations, and we use these formulas to calculate the expected outcomes of experiments. But, in order to be able to compare the results of our calculations with actual observations, more than sheer mathematics is needed. Physics is also an edifice founded on concepts, and the concepts are entwined as much with our world of experience as with mathematics. Divorced from everyday language, notions and experiences, the profession would bear little resemblance to what we today call physics. Then we would just have pure mathematics! The Greek word $\phi\upsilon\sigma\iota\varsigma$ ("physis") means *the nature* and physics is a part of *natural* science.

People are different. My experience is that some are fascinated primarily by mathematics and the laws of physics, while others are thrilled by the phenomena in themselves. Some others are equally intrigued by both these facets. In this book, I will try to present formalism as well as phenomena, because—as stated above—it is the combination that creates physics (Fig. 1.1)! A good physicist should be in close

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Fig. 1.1 Oscillations and waves are woven into a host of phenomena we experience every single day. Based on fairly general principles, we can explain why the most common rainbow has invariably a radius of 40−42° and is red outward, and the sky just outside the rainbow is slightly darker than that just inside. You already knew this, but did you know that you can extinguish the light from a rainbow almost completely (but not for the full rainbow simultaneously), as in the right part of the figure, by using a linear polarization filter? The physics behind this is one of the many themes covered in this textbook

contact with phenomena as well as formalism. For practical reasons and with an eye on the size of the book, I have chosen to place a lot of emphasis on mathematics for some of the phenomena presented here, while other parts are almost without mathematics.

Mathematics comes in two different ways. The movement of, for example, a guitar string can be described mathematically as a function of position and time. The function is a solution of a differential equation. Such a description is fine enough but has an ad hoc role. If we know the amplitude at a certain time, we can predict the amplitude at a later instant. Such a description is a necessity for further analysis, but really has little interest beyond this. In the mechanics, this is called a *kinematic* description.

It is often said that *in physics we try to understand how nature works*. We are therefore not satisfied by a mere mathematical description of the movement of the guitar string. We want to go a little deeper than this level of description. How can we “explain” that a thin steel string under such-and-such tension actually gives the tone C when it is plucked? The fascinating fact is that with the help of relatively few and simple physical laws we are able to explain many and seemingly diverse phenomena. That gives an added satisfaction. We will call this a *mechanical* or *dynamic* description.

Mathematics has traditionally been accorded, in my opinion, overmuch space, compared with the challenge of understanding mechanisms. This is due in part to the fact that we have been using, by and large, analytical mathematical methods for solving the differential equations that emerge. To be sure, when we use analytical methods, we must penetrate the underlying mechanisms for the sake of deducing the equations that portray the phenomena. However, the focus is quickly shifted to the challenges of solving the differential equation and discussing the analytical solution we deduce.

This approach has several limitations. First of all, the attention is diverted from the content of the governing equations, wherein lie the crucial mechanisms responsible for the formation of a wave. Secondly, there are only a handful of simplified cases we are able to cope with, and most of the other equations are intractable by analytical means. We often have to settle for solutions satisfying simplified boundary conditions and/or solutions that only apply after the transient phase has expired.

This means that a worrying fraction of many generations of physicists are left with simplified images of oscillations and waves and believe that these images are valid in general. For example, according to my experience, many physicists seem to think that electromagnetic waves are generally synonymous with plane electromagnetic waves. They assume that this simplified solution is a general formula that can be used everywhere. Focusing on numerical methods of solution makes it easier to understand why this is incorrect.

1.2 Numerical Methods

Since about the year 2000, a dramatic transformation of physical education in the world has taken place. Students are now used to using computers and just about everyone has their own or have easy access to a computer. Computer programs and programming tools have become much better than they were a few decades ago, and advanced and systematic numerical methods are now widely available. This means that bachelor students early in their study can apply methods as advanced as those previously used only in narrow research areas at master's and Ph.D. level. That means they can work on physics in a different and more exciting way than before.

Admittedly, we also need to set up and solve differential equations, but numerical solution methods greatly simplify the work. The consequence is that we can play around, describing different mechanisms in different ways and studying how the solutions depend on the models we start with. Furthermore, numerical solution methods open the door to many more real-life issues than was possible before, because an "ugly" differential equation is not significantly harder to solve numerically than a simple one. For example, we could write down a nonlinear description of friction and get the results almost as easily as without friction, whereas the problem is not amenable to a purely analytical method of solution.

This means that we can now place less emphasis on different solution strategies for differential equations and spend the time so saved for dealing with more real-life issues. I myself belong to a generation which learned to find the square root of a number by direct calculation. After electronic calculators came on the market, I have had no need for this knowledge. We are now in a similar phase in physics and mathematics. For example, if we use the Maple or Mathematica computer programs, we get analytical expressions for a wealth of differential equations, and if a differential equation does not have a straightforward analytical solution, the problem can be solved numerically. Some skills from previous years therefore have less value today, while other skills have become more valuable.

This book was written during the upheaval period, during which we switched from using exclusively analytical methods in bachelor courses to a situation where computers are included as a natural aid both educationally and professionally. We will benefit directly from this not only for building up a competence that everyone will be happy to employ in professional life, but also by using it as an educational tool for enhancing our understanding of the subject matter. With numerical calculations, we can focus more easily on the algorithms, basic equations, than with analytical methods. In addition, we can address a wealth of interesting issues we could not study just by analytical methods, which contributes to increased understanding. Numerical methods also allow us to analyse functions/signals in an elegant way, so that we can now get much more relevant information than we could with the methods available earlier.

Using numerical methods is also more interesting, because it enables us to provide "research-based teaching" more easily. Students will be able to make calculations similar to those actually done in research today. There are plenty of themes to address because a huge development in different wave-based phenomena is underway. For example, we can use multiple transducers located in an array for ultrasound diagnostics, oil leakage, sonar and radar technology. In all these examples, well-defined phase differences are used to produce spatial variations in elegant ways. Furthermore, in so-called photonic crystals and other hi-tech structures at the nanoscale, we can achieve better resolution in measurements than before, even better than the theoretical limits we believed to be unreachable just a few years ago. Furthermore, today we utilize nonlinear processes that were not known a few decades ago. A lot of exciting things are happening in physics now, and many of you will meet the topics and methods treated in this book, even after graduation.

1.2.1 Supporting Material

A "Supplementary material" web page at http://www.physics.uio.no/pow is available for the readers of this book. The page will offer the code of the computer programs (both Matlab and Python versions), data files you need for some problems, a few videos, and we plan to post reported errors and give information on how to report errors and suggestions for improvements.

1.2.2 Supporting Literature

Many books have been written about oscillations and waves, but none of the previous texts covers the same combination of subjects as the present book. It is often useful to read how other authors have treated a particular topic, and for this reason, we recommend that you consult, while reading this book, a few other books and check, for example, Wikipedia and other relatively serious material on the Web. Here are some books that may be of interest:

- Richard Fitzpatrick: "Oscillations and Waves: An introduction". CRC Press, 2013.
- H. J. Pain: "The Physics of Vibrations and Waves". 6th Ed. Wiley, 2005.
- A. P. French: "Vibrations and Waves". W. W. Norton & Company, 1971.
- Daniel Fleisch: "A Student's Guide to Maxwell's Equations". Cambridge University Press, 2008.
- Sir James Jeans: "Science and Music". Dover, 1968 (first published 1937).
- Eugene Hecht: "Optics", 5th Ed. Addison Wesley, 2016.
- Geoffrey Brooker: "Modern Classical Optics". Oxford University Press, 2003.
- Grant R. Fowles: "Introduction to Modern Optics". 2nd Ed. Dover Publications, 1975.
- Ian Kenyon: "The Light Fantastic". 2nd Ed. Oxford University Press, 2010.
- Ajoy Ghatak: Optics, 6th Ed., McGraw Hill Education, New Delhi, 2017.
- Karl Dieter Möller: "Optics. Learning by Computing, with Model Examples Using MathCad, Matlab, Mathematica, and Maple". 2nd Ed. Springer 2007.
- Peter Coles: "From Cosmos to Chaos". Oxford University Press, 2010.
- Jens Jørgen Dammerud: "Elektroakustikk, romakustikk, design og evaluering av lydsystemer". http://ac4music.wordpress.com, 2014.
- Jonas Persson: "Vågrörelseslära, akustik och optik". Studentlitteratur, 2007.