Preface

Those brave souls taking up physics for study and an introductory textbook have one thing in common: they face the same problem — although from different vantage points — the lack of a yet to be established convention on how to communicate. Everyday English is too imprecise, students come from school prepared to widely different degrees and there are grossly misguided ideas concerning what studying physics is all about. But we are all human beings, have all been for a walk in the fields, have marveled at the night sky, can visualize things with our eyes closed, possess the ability to wonder and are familiar with the question "Why ? ". Doing Physics means to never cease asking this question.

Unraveling the processes of Nature takes place at a desk. Understanding means reduction to phenomena already known. This is done with equations, sketches, and calculations. Every symbol that appears on paper carries meaning. The art of understanding develops from the characters in formulae just like notes in a musical score can be turned into music. The art of understanding is a practical skill; its tools are the symbols in the formulae of "calculation with meaning". The object of this book is to explicate these symbols and to make their meaning transparent. It can accompany the reader only so far; only by trying things out oneself, by practicing, practicing and practicing more, will the decoder of notes become a pianist.

No particularly advanced degree of school knowledge is presumed. What an angle is, e.g. or why the theorem of Pythagoras holds will be explained. Perhaps — and that would be nice — parts from the first few chapters of the book may be used by teachers and students in advanced classes in high schools. In subsequent chapters other aspects will take precedence: efficiency (brief is beautiful; visualizing things saves time), elegance (hopefully; else, try to improve on it!) and the ability to discriminate between fundamentals, derivations and specialized applications (only in this way can one cope with the by now enormous field of physics). This places high demands now on the "reader without prior knowledge": the ability to reflect, imagination, being honest with oneself and a tremendous desire to write down by oneself, try out and improve all ideas accessible by the formulae — until one acquires the feeling of having invented them on one's own.

The book is based on a course for first–year students at Hannover University/Germany (lecture and exercises) under the heading *Calculational Methods of Physics*. This title is an overstatement. Formerly it was called *Supplementary*

Mathematics Course. Nothing in this title was quite correct. But everyone knew what it meant. With the title of this book it is just the opposite. It is correct — but one doesn't quite understand it. That is because it contains two words that are foreign. It is not uncommon for these two words

Theoretical Physics

to be thoroughly misunderstood. Let us first "translate" the noun. What is remarkable about physics is that it exists at all. And it has only existed – in the proper sense of the term – for about 300 years. We have known about regularities in Nature's processes for a long time — ever since man was able to record and communicate his observations. Under identical conditions processes recur in exactly the same manner. Nature behaves mathematically. What was really exciting was the realization that there is *unity* in the mathematics of these processes. There is only *one* mathematics involved, valid for all phenomena. This may sound incredible. One is entitled to have doubts (they will be removed during one's studies). If the statement is correct, though, then feelings of awe are called for at this point. That a unique "nature–mathematics" does exist is Nature's wonder No.1. Mathematics is based on axioms (a few initial statements that determine everything that follows from them). The axioms of the "nature–mathematics" are called *first principles*. If we know the world's first principles we can — in principle — understand all its phenomena. Understanding is now equivalent to reduction to these axioms. The initial first principle (it was incomplete and not quite right, but after all it was the first) was formulated by Newton in 1687.

We shall now try to give a definition of *physics* (in a way not to be found in any dictionary):

> Physics is the (one) fundamental natural science that, on one hand, looks for the (small number of correct and exhaustive) *first principles* of "nature–mathematics" and, on the other hand, seeks to understand the phenomena of Nature by demonstrating them to be inevitable consequences of such principles (as far as they are already known).

The back side of this definition is somewhat malicious. As soon as one ceases to have anything to do with Nature's first principles, one is no longer dealing with physics at all. The reader is invited to reflect on how well our definition differentiates physics from other natural sciences. It is not "arrogant" but certainly very high-brow. Biologists and chemists can rightly reply that we do not yet understand even a blade of grass or the properties of water. For the time being that is still too difficult.

Physics and calculating are thus inseparable. Mathematicians do mathematics; physicists do "nature–mathematics". At worst, the former may contain a logical error. The latter, in contrast, can also be wrong because it does not conform to the actual behavior of Nature. Physics thus has two supreme judges: logic *and* reality. Maybe that is why it is commonly regarded as being "difficult". One can be ridiculed all too easily for producing a solution to an exercise that is (almost) completely logical but nonetheless wrong. How come? There were two solutions to the problem, for instance, but only one made sense.

Now it is easy to understand the adjective. It refers to a division of labor. Experimental physicists spend their working lives closer to natural phenomena and theoretical physicists closer to logic — and exclusively at their desks. The choice of the word "theory" is unfortunate. It seems to imply that one is free to invent the way the world is constituted, or that physics is just one way to interpret the world among many. No, every detail of our current knowledge of "nature–mathematics" has been examined and confirmed by thousands of physicists. Proof of even the slightest deviation will lead to a Nobel Prize. Theoretical physics comprises the most solid statements that man is able to express about Nature.

There is only one way to get to the heart of things. The inner harmony of Nature is accessible only to those who have mastered the art of "calculation with meaning". This means to have a firm grasp of its

Analytical Tools

to make use of them, to work and think in terms of them. These tools and their symbols are also those of mathematics. They appear on paper. The comparison with the pianist fails here because now *everything* takes place on paper. We are both composer and pianist. To each of the following 16 chapters one may naturally assign a typical symbol in a free and easy manner. In "cuneiform script", the contents, for example, looks like this:

$$\vec{\ } \qquad \dot{\vec{\ }} \qquad m\ddot{\vec{r}} \qquad DHD^T \qquad \mathrm{e}^x \qquad \int \qquad Ly = f$$

$$\nabla \qquad \oint \qquad \mathrm{e}^{tD\Delta} \qquad \vec{E} \times \vec{B} \qquad \mathrm{e}^{\mathrm{i}kx} \qquad \delta S \qquad -\sum p \ln(p)$$

$$mc^2 \qquad \mathrm{i}\hbar\dot{\psi} \qquad .$$

These symbols (and many more) are like building blocks out of a construction kit. They are capable of causing an incredibly large amount of work. By means of these building blocks Nature can be partially "reconstructed" and — even more importantly — predicted.

Theoretical physics is something one *does.* I sit at my desk and consider a certain natural process which I should like to comprehend. So I start to *draw.* That is a good thing. We did not acquire the ability to draw directly by Darwinian selection so some effort is required in order to actually do it. Sketches nearly always have to be improved. The same applies to calculations. So I use a pencil. It is well suited to the way we work: noting something down — reflecting — revising. I want to be able to erase. I need to feel free when I draw and in order to draw, and when I calculate in order to facilitate the next step of the calculation.

Another advantage of the pencil is that it can be sharpened. If necessary one can easily distinguish between four different letter sizes (imagine a subscript with index on index on index). We write on *blank* paper. The reader can easily prove to himself (and his old school-teacher) how much squared paper contravenes the way we work. The world is not made up of squares and all types of templates are detrimental for us. At venerable universities, lecturers are often reluctant to give this type of advice. However, when you study physics it is particularly important to vary your patterns of thinking and proceeding until you have found the ones that suit you best.

All the analytical tools that are dealt with in the following 14 chapters will indeed be constantly required in the course of your studies. The majority (99%?) of the calculations used in the natural sciences are based on them. At the end of each chapter, there is time for contemplation and putting things into a general perspective (first work, then play). The character of a training program (lectures *and* exercises) has been preserved as far as possible. So one will find references (at unexpected places) in the text to the home exercises contained in part IV that now can — and must — be mastered. They demarcate the material for a week. If this material seems unduly large, it is because the book goes beyond the scope of the lecture course.

The exercises are small research projects. They are to be worked out individually and unassisted. The moment of truth will come in Part IV. Please: Don't ever complain that it took "15 hours" to solve a particular problem. It will only prompt a wry smile and comments such as: "Was the radio playing ?", "Oh yes, my last problem took 150 hours and a sleepless night" or "Then you just still needed to spend 15 hours on it". And, without quotation marks: no time spent on exercises is ever wasted. They *are* your course.

Good luck !

I am very grateful to Dr. A. Ziegler (APL in Osnabrück/Germany) and to A. A. Ludl (PhD in Paris). A. Ziegler translated Preface, Contents, § 1.1 and Chapter 9, while chapters 15 and 16 are due to A. A. Ludl. Since the remaining 280 pages were compiled by myself they could contain one or the other unusualness in English usage. If so I apologize for that.

Thankfully, Marina Forlizzi and Neil Ashby detected and corrected various errors throughout the main text.

I also wish to thank Klaus Horn (Verlag Europa–Lehrmittel) for his unhesitant assistance during the production of the book.

Hannover, in September 2015 *Hermann Schulz*