Preface

We have conceived this book for curious students and young researchers who wish to understand the role that several branches of Physics and Mathematics, taught at the undergraduate and graduate level, play in the carrying out of current experiments. Among the above branches, we focused our attention on the interaction of electromagnetic radiation with single crystals, the basic elements of linear elasticity for anisotropic media, the propagation of thermal energy, the anti-vibration mounting systems and the analysis and interpolation of the collected data. The literature includes excellent books treating the interdependence of these topics but the peculiarity of the present work is that all the considered subjects have been dealt with and solved during the carrying out of *one* single experiment of very high accuracy; the experiment we are referring to is currently *in fieri* at INRIM and is about the redetermination of the Avogadro constant N_A, which is one of the fundamental physical constants. It represents the link between macro and micro physics and the attention towards this constant has increased since 1965 with the construction of the first X-ray interferometer. In fact, this interferometer made it possible to measure the lattice parameter of a silicon single crystal, a quantity appearing in the formula for N_A, with unprecedented accuracy. For this reason, and considering that N_A plays a cardinal role in the redefinition and the realization of the mass unit or of the mole unit in the International System of Units (SI), the BIPM has established an *ad hoc group* having the purpose of reducing the relative uncertainty $u_r(N_A) \approx 5 \times 10^{-8}$, by a factor of two, exploiting innovating methods. Therefore, the aim of the present book is to illustrate how the basic laws of Physics are applied to describe the behaviour of some of the involved quantities and to point out the followed mathematical and physical reasoning.

In the Introduction we clarify the motivations justifying the efforts of several international laboratories involved in the International Avogadro Coordination project, summarize briefly the historical evolution of this constant, illustrate the XRCD method (X-Ray Crystal Density) based on the formula containing the three physical quantities to be measured, and focus the attention on some of the most innovative aspects of the experimental setup and the computational tools exploited to simulate the behaviour of the quantities under observation (for example, the electric

displacement vector, the elastic constants, the temperature, the amplitude of parasitic vibrations, the volume of silicon spheres).

In writing this book we tried our best to illustrate all the quantities and the analytical background following a *step by step method*. The reader will realize that there is no sharp distinction between the two possible audiences of undergraduates and graduates; this is due to the non uniform distribution of the conceptual difficulties in the single chapters. For example, in dealing with the behaviour of a body with six degrees of freedom when subjected to base motion, we have found appropriate to start from the *humble spring*, running the risk to be pedantic, and then, to deduce and solve the relevant system of differential equations. In this way, one is not only able to handle or solve the equation but can see them *at work* understanding the less evident physical aspects they are describing. The different topics, although pertaining to one single experiment, are of wide and general interest and can be grasped by students having a basic knowledge of classic physics and calculus. We have no pretension to present the ultimate results, we just hope to describe the basic but fundamental bricks.

The book is organized in six chapters, the content of which will be summarized in the Introduction. Each chapter develops the concepts by starting from an elementary level and then, through the necessary intermediate steps, it proceeds to a more advanced level, adequate to tackle the real problems. Consequently, two phases in each chapter are foreseen.

The first concerns the necessity of identifying the main observables under examination and of deducing the relevant model, usually governed by an ordinary or a partial differential equation. This is of primary importance because we are convinced that the logical processes followed by physicist-mathematicians (for example, from Fourier, Lagrange, … to Takagi), to deduct the equations bearing their name, deserve careful study to appreciate their implications. The second phase is not of minor importance; in fact, even though it is true that basic laws represent the starting point, it is also essential to apply the equations we have got and follow their development along the traced path. However, as in real situations it is almost always unavoidable to introduce simplifying hypotheses, we have to look for approximate solutions. For this reason numerical methods, although well known since the 19th century, have received an impressive impetus with the advent of computers and, in the last decades, they have received a further contribution from auxiliary tools known as Computer Aided Systems; these tools have the objective of simplifying the traditional computational burden. Among them, we have chosen *MATHEMATICA*® because it conjugates symbolic, numerical and graphic methods besides stimulating experimentation. To show its connection in the context, we have prepared nearly fifty programs, called notebooks, written according to the Mathematica rules; they are distributed in the chapters with the aim to expand the level of comprehension. Notwithstanding their presence, we emphasize that the book is perfectly usable without *MATHEMATICA*®. Nevertheless, we remind the reader that a judicious use of the code is beneficial. In fact, the efforts and time required to learn this code are rewarded by a more complete view of the physics behind the formulae and a better understanding of the implied computational problems; we could add that we

come close to violating the first principle of Thermodynamics, in the sense that the energies spent along the learning curve are very well compensated. In addition, to facilitate their use, we have striven to write clear notebooks to be interpreted with an elementary background of *MATHEMATICA*® built-in commands. The notebooks can be freely downloaded from the repository (http://extras.springer.com) together with a free program which allows their interpretation. We underline also that *MATH-EMATICA*® is a free choice of the authors and any other Computer Aided System can be used according to the experience and preference of the reader.

We have also to specify that we have used not only this package during the project about N_A, in particular when the complexity of the model forced us to employ commercial codes based on finite element methods. In fact, at present *MATHEMATICA*® is only in progress to face very large-scale system design; nevertheless, this limitation does not reduce its effectiveness in the solution of the encountered problems.

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