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S. G. Karshenboim
E. Peik
(Eds.)

Astrophysics, Clocks and Fundamental Constants

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Astrophysics, Clocks and Fundamental Constants

Springer

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Foreword

We know that we live in an expanding and changing universe, but nevertheless we prefer some solid foundations upon which to base our reasoning. This idea is reflected in the introduction of quantities that we call the "fundamental physical constants". These constants do, as John D. Barrow said, "capture at once our greatest knowledge and our greatest ignorance about the universe". The interrelations between them give us hints where to look for underlying common foundations of phenomena that are observed in different branches of physics. At the same time, we also call these quantities "fundamental" because we have not so far been able to deduce their numerical values from a deeper level of understanding.

As supposedly universal and invariable quantities, the fundamental constants constitute an essential pillar for the definition and representation of the SI units. The replacement of man-made artefacts by quantum standards for the representation of the units has led to enormous progress in precision measurements. Provided a sufficient theoretical understanding of the quantum standard is available, its output may be linked to the fundamental constants and that is why many metrology institutes, like the PTB, are actively involved in the high precision determinations of these values.

While for practical purposes we would like to trust in the universality and invariability of the constants, as physicists we may be urged to challenge these postulates. Possible variations in time or space would have far reaching consequences and may point the way to a unified theory of the fundamental interactions and the establishment of a quantum theory of space-time. Discrepancies with respect to the presently believed interrelations (e.g. between the value of the Planck constant h from electrical measurements and from the Avogadro project with the silicon single-crystal method) may lead to new insights as well.

The study of the fundamental constants and their possible variation is an interdisciplinary and "global" task, i.e. involving experts from very different fields of physics all over the world. It is therefore essential to bring scientists from these different fields together in symposia like "Astrophysics, Clocks and Fundamental Constants". Fortunately, the speakers at that conference agreed to make their contributions available to a wider audience and contributed to this book. Astrophysics provides information about the state of the universe in the remote past and about regions of space far away from us, geophysics teaches us the history of our planet, laboratory experiments (especially with atomic clocks, as frequency and time are the most precisely measurable physical quantities)

can furnish a precise snapshot of present temporal derivatives, whereas satellite missions may be used to probe the solar system with precision instruments. This book presents a collection of excellent reviews on these topics.

Physikalisch-Technische Bundesanstalt
Braunschweig
May 2004

Ernst O. Göbel

Preface

Fundamental physical constants play an important role in modern physics. The "old fashioned" celestial mechanics knew only one such constant, the Newtonian constant of gravitation G. Now the list of basic universal constants is much longer. The speed of light c is a basic constant of relativistic physics and its value is a part of the international system of SI units. It is not even possible to imagine contemporary physics without the fine structure constant α, the Planck constant $\hbar$, the electron mass m_e, the Rydberg constant Ry, etc. A frequent appearance of the same constant in different branches of physics demonstrates its universality and significance for fundamental physics and numerous applications.

Most of the fundamental constants entered physics in the late nineteenth or early twentieth century. The early twentieth century was not only a time when a substantial part of the constants were introduced into modern physics with the establishment of quantum physics but that was also the time when the question of the constancy of the "constants" was raised by P.A.M. Dirac. He considered the problem in the context of a comparison of the electromagnetic and gravitational interactions. Dirac's original idea is now rather out of consideration; however, the link between the grand unification of all basic interactions and a variability of their coupling constants has survived and still seems to be important.

A search for variations in the values of fundamental physical constants gives us a rare but excellent example of the strong interplay between new fundamental physics and the development of applied studies such as frequency metrology and space navigation.

Our book is formed of invited reviews presented at an international conference "Astrophysics, Clocks and Fundamental Constants" organized as the 302nd WE-Heraeus-Seminar which took place in June, 2003, in Bad Honnef in Germany. We tried to combine in our meeting the contributions on

- *Astrophysics*, a science which among other branches of physics is most involved in the study of the time evolution of our world; it also allows us to probe objects located far away from us in time and space;
- *Fundamental Constants*, which involves a broad variety of questions ranging from deeply fundamental properties of Nature to the development of new standards;
- *Clocks*, the modern frequency standards, which offer the most accurate measurements with an accuracy superseding any other measurements by several

orders of magnitude and therefore provide the most favourable opportunity for a search of a possible time variation of fundamental constants in the laboratory.

The field of variations of fundamental constants involves various pieces of theory and experiments from so many parts of physics that there may be no single person in the world who is a real expert in the field. We had the hope, however, that the conference participants all together form a kind of collective expert. We think now that we were right and that this book has been written by such an expert covering most aspects of the field related to astrophysics, cosmology, geochemistry, molecular, atomic, nuclear and particle physics, quantum field theory, space science and metrology. The contributions to the book have been prepared with the strongly interdisciplinary character of the conference in mind. It was our intention to encourage an exchange between the various specialized subfields so that the book addresses a wide audience of physicists from any of these fields as well as students looking for an introduction into this exciting and topical area of research.

We live in an expanding universe at a time when even the number of dimensions of our world is not a completely clear problem and in experiencing the changing Nature we may wonder why the fundamental constants should be left unchanged. Should they?

We are grateful to the WE-Heraeus-Stiftung for their support and substantial help in organizing the conference.

Braunschweig
May 2004

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