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Eleftherios N. Economou

A Short Journey from Quarks to the Universe

Selected Solutions

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SpringerBriefs in Physics

Volume 1

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Additional material to this book can be downloaded from http://extra.springer.com

ISSN 2191-5423 e-ISSN 2191-5431
ISBN 978-3-642-20088-5 e-ISBN 978-3-642-20089-2
DOI 10.1007/978-3-642-20089-2
Springer Heidelberg Dordrecht London New York

Cover design: eStudio Calamar, Berlin/Figueres

Printed on acid-free paper

Springer is part of Springer Science+Business Media (www.springer.com)

There is, of course, an immense liberating role of Science at the central existential level. It is what Aristotle was saying about "θαυμάζειν". Science humanizes us, liberates us from our animal instincts, just because it makes us wondering and at the same time desiring to explain… Yet it shows us our limits and our mortality… Thus Science is something immeasurably precious…. Science can help us approach anew the real poetic and mythical dimension of human existence.

C. Castoriadis

To Christos, Eleni, Zinovia, Yiannis, and Evropi with wishes "για καλή στράτα" in life's pathway.

Suggested by A., of course

Preface

This short book grew out of lectures presented to different audiences (physics students, physicists, material scientists, engineers) and on various occasions (colloquia and seminars in physics and other departments, conferences, special events). The main purpose of these lectures and, obviously, of the present book is to show that basic formulae concerning the various structures of the *physical world* pop out quickly, if some *basic ideas*, the *universal physical constants, and dimensional considerations* are exploited. Of course, as R. Feynman pointed out, "a little thinking has to be applied too".

The basic ideas include the three cornerstones of science, namely the atomic idea, the wave-particle duality, and the minimization of free energy as the necessary and sufficient condition for equilibrium (these are presented in Chaps. 2, 3, and 4 respectively). These fundamental ideas exhibit their worth when accompanied by the values of the physical constants: the universal ones, $\hbar$, c, the coupling constants of the four interactions, G, e, g_w, g_s and the masses of the elementary particles, m_p, m_n, m_e, m_w,... An important consequence of the atomic idea is that the relevant (for each case) physical constants will appear in the quantities characterizing the various structures of the world (microscopic or *macroscopic*). Combining this last observation—often overlooked—with dimensional analysis, presented in Chap. 5, and "a little thinking", one can obtain, in several cases, an amazing short-cut derivation of formulae concerning the various structures of nature from the smallest (baryons and mesons) to the whole Universe, as shown in Chaps. 6–13. In each one of these 8 chapters, in parallel with a demonstration of the method just outlined, a *condensed* (sometimes too condensed) introduction to the relevant subject matter together with a few physical remarks are presented.

I must admit that the main fronts on which our horizons are widened, namely the *small*, the *large*, and the *complex* could not be treated even remotely adequately in this short book. Actually the *complex*, as represented by the living matter, was too complex for our simple method; so it was left out completely (however, see the epilogue). The *large* (cosmology) and the *small* (elementary particles) tend to converge to a unified subject (the snake in Fig. 1.1, p. 2, is biting

its tail) fed with novel observational data from special instruments mounted usually on satellites, and boosted by high experimental expectations from the Large Hadron Collider. Nevertheless, in these fields there are several open fundamental questions concerning conditions well beyond our present or near future experimental capabilities. This vacuum of confirmed knowledge is filled with new, intriguing, imaginative ideas and novel proposed theories (such as supersymmetry, string theory, M-theory, see reference [P1]) which, if established, will radically change our world view. In spite of the wider interest in these ideas and theories and their high intellectual value, I decided for several reasons to restrict myself in the present book to experimentally or observationally tested ideas and theories.

The intended readers of this book are senior undergraduate or graduate students in Physics, Engineering, Applied Mathematics, Chemistry, and Material Science. They may find the book a useful supplement to their courses as a concise overall picture of the physical world. Research physicists, physics teachers, and other scientists may also find this short book intellectually stimulating and entertaining. The required background is no more than a *working* familiarity with the first year Science or Engineering material.

I am deeply indebted to my colleague, Prof. V. Charmandaris, for his encouragement during the writing of this book and for reading my entire manuscript and making many useful suggestions. Of course, whatever misprints or misrepresentations remained are my own responsibility only. I am also grateful to Ms Maria Dimitriadi for her invaluable help in bringing my manuscript to its final form.

January 2011 Heraklio

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Chapter 1
Introduction: The World According to Physics

Ah, but a man's reach should exceed his grasp. Or what's a heaven for?

R. Browning

Abstract In this introductory chapter the subject matter as well as the methodology of Physics are briefly presented together with a list of the basic structures of matter.

Keywords Natural Philosophy · Structures of matter · Origin of matter · Nature of Physics

Modern-era Physics started as Natural Philosophy. As this former name implies, Physics is built (and continues to be developed) around the age-old, yet ever-present questions:

- What the World and its parts are made of? How?
- Is there a hidden underlying simplicity in its immense complexity and diversity?

The first question implies that the subject matter of Physics is the World, both natural and man-made; from its smallest constituent to the whole Universe (see Fig. 1.1 and Table 1.1 p. 3). In this sense, Physics is encompassing the other natural sciences (such as Chemistry and Biology) and even Engineering, while at the same time it provides also their foundation. What allows Physics to have this dual role is its characteristic methodology. The latter is precise and quantitative, yet capable of abstraction (therefore mathematical). It is based on observations and well controlled experiments both as sources of ideas and as tests for falsification or tentative confirmations of proposed and—even—established theories. Moreover, as the second question suggests, the methodology of physics requires the formulation of a few fundamental quantitative relations on which everything else is based. These features of the methodology of Physics account for its role as foundation of every other science and engineering, but also for its limited

E. N. Economou, *A Short Journey from Quarks to the Universe*,
SpringerBriefs in Physics, 1, DOI: 10.1007/978-3-642-20089-2_1,

penetration into very complex, yet very important, parts of the World (such as the molecular and the biological worlds). This leaves plenty of space to more specialized sciences such as Chemistry and Biology and, of course, Engineering.

Over the last 50 years or so Physics is actively concerned over another fundamental, age-old, but much more difficult question which stretches its methodology to the limit:

- How did the World start, how did it evolve, and where is it going?

Detailed observational data, such as the recession of distant galaxies at a speed proportional to their distance from Earth, the spectral and angular distribution of the Cosmic Background Microwave Radiation, etc., combined with established physical theories, allowed us to reconstruct roughly some of the main events in the history of the Universe. Naturally, other crucial events, including the emergence of life, remain unknown and they are the subject of current research. Subject of current theoretical research is also the development of a successful quantum theory of gravity, which is expected to let us approach the very moment of the genesis of the Universe.

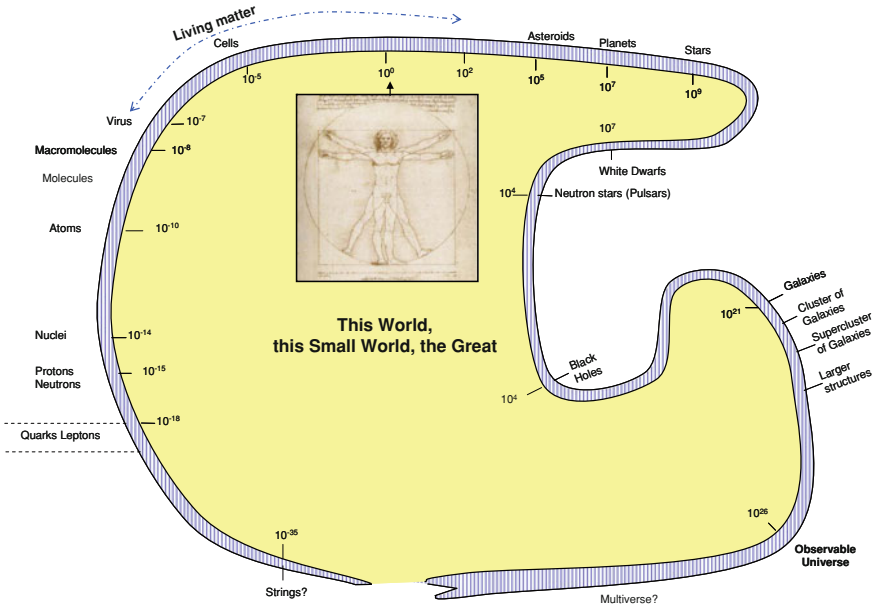

Fig. 1.1 The main structures of matter from the smallest to the largest size (*clockwise)* and the suspected connection of the two extremes (see Ref. [1.2]). The indicated sizes are in meters

Table 1.1 Levels of the structure of matter (see also [1.1])

Level of the structure of matter	Length scale (in m)	Constituents	Interaction(s) responsible for the structure
Quarks	$<10^{-18}$	It seems to be elementary	–
Electron	$<10^{-18}$	It seems to be elementary	–
Proton	10^{-15}	u,u,d quarks	Strong, weak,, E/M
Neutron	10^{-15}	u,d,d quarks	Strong, weak,, E/M
Nuclei	10^{-15}–10^{-14}	Protons, neutrons	Strong, E/M, weak,
Atoms	10^{-10}	Nucleus, electrons	E/M
Molecules	$>10^{-10}$	Atoms and/or ions and electrons	E/M
Solids (primitive cell)	$>10^{-10}$	Atoms and/or ions and electrons	E/M
Cells	$\geq 10^{-6}$	Molecules	E/M
Biological entities (e.g., Homo Sapiens)	10^{-8}–10^{2} (10^{0})	Molecules, cells, tissues, organs, microbes	E/M
Planets	10^{6}–10^{7}	Solids, liquids, gases	E/M, Gravitational
Stars	10^{9}	Electrons, nuclei, ions, photons	Gravitational, strong, weak, E/M
White dwarfs	10^{7}	Nuclei, electrons	Gravitational
Neutron stars	10^{4}	Neutrons and some protons and electrons	Gravitational
Astrophysical black holes	10^{4}	?	Gravitational
Galaxies	10^{21}	Stars, ordinary and dark matter, photons, neutrinos	Gravitational
Observable universe	10^{26}	Galaxies, dark matter, dark energy	Gravitational, others?

In concluding these introductory remarks, we present below some of the various branches of Physics and their correspondence and/or overlap with more specialized sciences as well as some examples of the impact of Physics on important technologies: