This book is a popular introduction to modern natural science and provides an insight into the advanced and expensive technology that is required in the exploration of the micro-world, a world too small for the eye to see. This is the domain of the living cell, and even smaller entities, the basic building blocks of all matter: quarks, atoms and molecules.

It is possible with modern technology to obtain images of objects as small as an individual atom. It is even possible to hold one atom in place and study it individually. This book explains, in non-technical language, how we obtain our knowledge of the micro-universe. With the help of many clear diagrams, it goes on to describe the structure of atoms, molecules and living cells as they are found in everyday objects, as well as in more exotic and dramatic forms of matter, such as antimatter, stars, and black holes.

OUT OF SIGHT

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from quarks to living cells

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To Eva and Inga–Lis

Contents

Preface

Our everyday world seems very familiar and ordinary to many of us. It is true that the blooming lilac, the spectrum of the rainbow, or the first snowflakes can evoke romantic memories, but we are often unaware that these events reflect movement and structure of constituents in a microworld that cannot be grasped through direct sensory observation.

In this microworld each drop of water, each grain of sand, each ant's egg is an entire world in itself, full of movement and interactions, with billions of elementary constituents.

It is through knowledge of the most minute constituents of matter and their interactions that we can gain a deeper insight into a world that, thanks to advances in technology, is now known and exploited more than ever. As a medical doctor gains knowledge of a patient's interior from the patterns built up by X-rays on photographic film, so we reconstruct the structure of cells, molecules and atoms from the patterns of the tracks of probing radiation particles.

Knowledge of the inner structure of matter raises difficult philosophical and religious points that affect our understanding of our place in the cosmos. Throughout history, human beings have endeavoured to make sense of the world and their perception of it. Many developed intuitive ideas, some of which are only just being investigated scientifically today. The introductory chapter of this book takes us on a concise journey through the history, and sometimes the realization, of the ideas on which our modern understanding of the microworld is based. Some of the topics covered in later chapters are introduced.

In Chapters 2 and 3, we discuss light and darkness, two concepts which seem entirely familiar to us. However, we have to enter into the totally unfamiliar world of electromagnetic radiation, of the massless particles called photons, and of atoms with their electron constituents, to really understand the nature of light and darkness.

We are all aware that the visible radiation that we call sunlight travels as a wave through space, and that it is therefore very similar to other waves (water waves, radio waves, etc.) in the way that it behaves. What

is astonishing is that, under certain conditions, visible radiation can act as if it were composed of particles. In Chapter 4, we enter the regime of invisible radiation, and we see how the phenomenon of wave–particle duality is exploited in many useful and interesting applications in today's technology. X-rays and gamma rays are types of invisible electromagnetic radiation which can be interpreted as either waves or photons. Particle radiation, on the other hand, is composed of massive particles such as neutrons, electrons and protons, but can also exhibit wave-like properties.

Everything around us is governed by forces which define all interactions as we know them. These (electromagnetism, gravitation, the strong and the weak nuclear forces) are explained in Chapter 5. If it were not for gravitation, our solar system and galaxy could not have evolved; the electromagnetic force is obviously important in such things as motors and electric lights, but it is also the force which binds atoms and molecules together; the nuclear force is possibly the most important of all, for, if it did not exist, subatomic particles would never have come together in the first moments of the Universe to form atomic nuclei, the cores of atoms which combine to form everything in our world.

It is matter, in all its most familiar forms and in its internal structure, that is the subject of Chapter 6. The different states of matter – solid, liquid, gas – define the world as we know it, and they are closely related to atomic and molecular structure. It is therefore important to understand how these structures are formed, how the very specialized world of electron densities and probability waves affect our perception of matter. Extending this idea, to understand matter fully, we also have to understand the constituents of atoms, the protons and neutrons, the electrons and eventually the quarks, and even antimatter.

Inanimate matter is perhaps easier to analyse in terms of its fundamental particles than living matter, as the fact that something is alive raises other considerations and perceptions. Chapter 7 describes the scientific aspects of life and the physical and chemical processes which govern it. The amazing 'master molecule of life', DNA, and the evolution of life on Earth are perhaps evocative issues but nevertheless they can be explained in terms of particles and forces in the microworld.

The final Chapter 8 presents an overview of the present knowledge of the evolution of the Universe and of how microcosmos and macrocosmos are closely related.

We will come to see that an appreciation of the past and present developments in science requires some familiarity with the different

classes of subatomic particles and their behaviour in and around us. Such knowledge is a logical starting point for the prevention and cure of disease, for a successful search for new sources of energy, food and materials, for re-establishing balanced ecological conditions on Earth, and for any strategy that aims to support the survival of mankind under desirable conditions.

The present book is an undemanding traveller's guide into the elusive world of cells, molecules and atoms. By probing these unfamiliar entities, we can hope to begin to understand the wonders of both the every-day world and the microworld.

In order to focus attention on principle rather than detail, the text contains many passages where described phenomena have been more or less oversimplified. In the real world, with its overwhelming variety of form and function, exceptions to the 'typical situation' are very common, to the extent that rules and general statements should always be considered with suspicion. This is obviously the case in sections that deal with cosmological, chemical and biological forms and functions, but the risk of oversimplification is always there, also in the most 'exact' physical sciences.

We shall use currently accepted international SI units; these and some useful symbols are defined in an Appendix. We often have to deal with very small or very large numbers, and find it then convenient to use standard notation; e.g. one million is denoted 10^6, etc.

We are grateful to colleagues who have advised us. In particular, we would like to mention contributions from Frank Arnold, Teddy Brunius, Anna Dyring, Sven H Olof Flyckt, Bengt Gustafsson, Yngve Hermodsson, Hidetsugu Ikegami, Anna Ka'ma'n, Stephen Lovesy, Héctor Rubinstein, Bengt Erik Rydén, and Hans-Richard Wersäll.

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Uppsala and Zurich

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