INVITATION TO

Contemporary Physics

2nd edition

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Preface

This book, first published some ten years ago, is an attempt to communicate to a non-specialist readership the main results in selected areas of modern-day physics. The last decade, which finally brought to a close an eventful century, was marked by significant advances in science and technology, achieved against the background of a shifting global political landscape.

In 1990, the Hubble Space Telescope, a 2.4 meter reflecting telescope, was deployed in earth orbit by the crew of the space shuttle Discovery; together with other orbiting observatories that followed close behind, it vastly expanded the horizons of our observable cosmos and worked to better define our universe and our place in it. That same year, the Human Genome Project was launched with the goal to identify the genes in human DNA and to determine the sequences of the base pairs that make it up; when this project is completed, not only will we know more about ourselves than ever before, but we will also have learned, in the process, the ways nature works. At about the same time, the HyperText Transfer Protocol (HTTP) was created that went on to become the standardized means of information transfer over computer networks, thereby inaugurating the information age and changing forever the way we live and work.

To reflect these important developments and a number of others, we have rewritten several chapters of the first edition and revised or updated all of the others. To these we have added three completely new chapters, on Bose–Einstein condensation, nanoscience, and quantum computation, three emerging areas with great potential for impact and applications in physics and beyond.

It is the objective of this book to present the essential concepts and observations of contemporary physics in language as simple as possible, without much mathematics but not without rigor. We have tried to write at a level that corresponds to a lower-undergraduate course, although, occasionally, the nature of the topic being discussed makes a more advanced treatment unavoidable.

As a textbook, it may be regarded as our modest contribution to a renewed approach to teaching introductory physics, in which concrete real-life examples happily cohabit with the usual elements of a traditional course. Whether taking a logical bottom-up or a thematic top-down approach, the physics teacher would want above all to keep her students interested and motivated: she will find here a source of fascinating topics at the research frontiers for open-classroom discussions or essay assignments.

This work also addresses the general reader who has a keen interest in physics. Physics, just as science in general, is not only about nature; it is also about people: it is a human pursuit, as old as civilization, as ingrained in our nature as our search for happiness. As a human activity, it shapes our intellect, molds our view of the world and of ourselves; but, for good or ill, it also affects our everyday life. It behoves us all, as ordinary citizens, to keep ourselves constantly informed of its progress and be alert to its issues and implications. Given the way science is built up and the pace at which advances are being made, those who stay behind are bound to fall farther and farther behind.

The reader should regard our book as an invitation to deeper meditation or further studies; you will find at the end of each chapter suggestions of possible avenues to more extended explorations. Mathematics is the natural language of physics, and, how ever hard we try, we cannot fully appreciate physics without equations. You may wish to check your understanding of the subject at the quantitative level by attempting to solve some of the end-of-chapter problems with the help, if necessary, of the hints scattered throughout the chapter or in Appendixes A–C and a peek or two at the solutions given in Appendix D.

C. S. Lam would like to thank Hoi-Kwong Lo and Patrick Hayden for their help on Chapter 6.

March 2003

Contents

Symmetry of Nature and Nature of Symmetry

1

1.1 What Is Symmetry That We Should Be Mindful of It?

Our immediate sense of symmetry comes from looking at objects around us. It may well be that the idea of symmetry is very primitive and comes naturally to the human mind. Perhaps the human mind can grasp it internally all by itself. But we shall leave these questions to the philosopher and to the artist. Instead, let us for a moment turn experimentalist and consider a sphere. Then we will be left in no doubt that we are in the presence of a perfect symmetry. We may view the sphere actively by turning it around every which way we like and find that it looks the same. We may view it passively by keeping the sphere fixed but shifting ourselves around it and find again that it looks just the same. It is this unchanging aspect of sameness against a changing viewpoint that symmetry is all about. But then we have to get sophisticated. We have to abstract the general idea of symmetry and make it free from this static and rather limited visual setting. This we must do and in doing so we will see more, and not less than the artist can, for all his sensitivity and imagination, ever hope to see. There is much more subtlety familiar in the world of physics than meets the eye. However, we will continue to use the same word for it: symmetry.

Symmetry suggests a sense of balance and proportion, of pattern and regularity, of harmony and beauty, and finally of purity and perfection. These synonyms just about sum up all our subjective reactions to the symmetries that abound in Nature, with her myriads of inanimate objects and life forms — the celestial spheres of the sun, the moon and the planets, the hexagonal snowflake with its six-fold symmetry, the five-fold symmetry of the starfish and of many a wild flower, the bilateral symmetry of the butterfly with its outstretched wings and of the man in his poise (Fig. 1.1). One even speaks of the fearful symmetry of the tiger. Examples will fill volumes. And as life imitates Art and Nature, we find something of it reflected in the art forms created by man — be it sculpture, architecture, painting, poetry or music. It is true though that in most of these cases the symmetry is only approximate. As a matter of fact the ancient Greeks used to intentionally

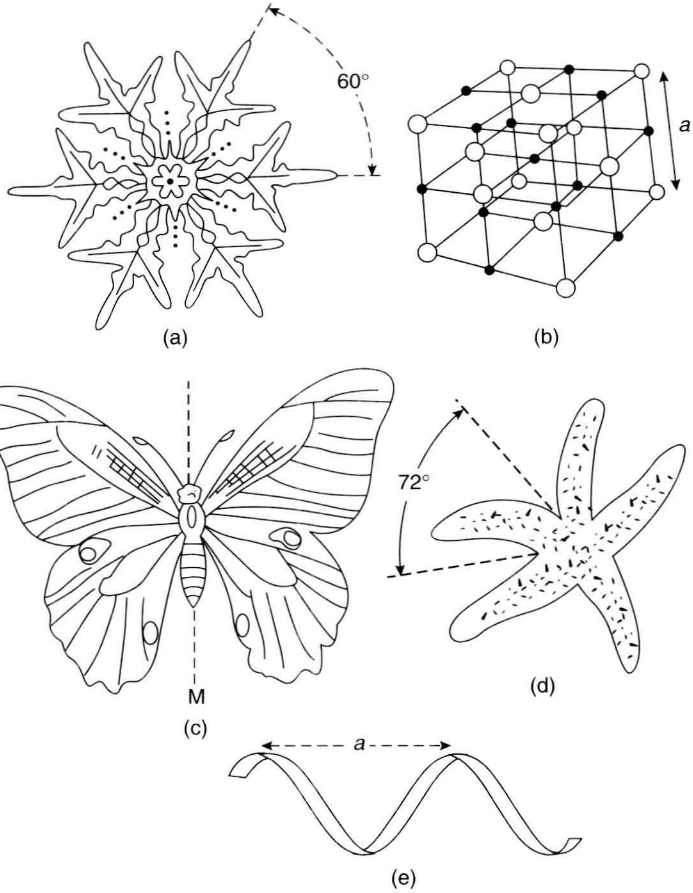

Figure 1.1: (a) Snowflake with six-fold axis; (b) crystal of common salt; (c) butterfly with bilateral symmetry; (d) starfish with five-fold axis; (e) right-handed helix.

and secretly introduce some degree of asymmetry in their otherwise symmetric designs. (After all, there is no perfect beauty that has not in it a certain *strangeness of proportion*). The fact remains, however, that the human mind is absolutely fascinated by symmetry. In physics, the term symmetry takes on an objective meaning which is much deeper and far more precise, almost more austere than our vague feelings of it can command. Let us get acquainted with it.

Now, we can hardly do better than just repeat the definition of symmetry given by the great German mathematician Hermann Weyl — a thing is symmetrical if there is something you can do to it so that after you have finished doing it, it looks the same as it did before. This is an operational definition — it can decide. The 'thing' here is the *object* of interest. What you do to it is called the *Symmetry operation* or *transformation*. And 'looks the same' is yet another