PHYSICS

BUILDING A WORLD VIEW

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To Solveiga, a little girl whose intense curiosity about her world and joy in building a world view was an inspiration.

Preface

Writing this book has been an exercise in translation. We have attempted to take the logic, the vocabulary, and even the feeling of physics and communicate them in an entirely different language. In some areas the physics is so abstract that it took creative bridges to span the gulf between the languages. Before beginning the translation, we had to decide on the overall content of the book. Our overriding concern was to choose those topics and ideas that are most appropriate for students who will only be taking one course in physics. We continually reminded ourselves that this is our only chance to describe the physics and to show how physicists develop and test their ideas. We chose the ones that we felt conveyed the essence of the physics world view.

A good job of translating requires expertise in both languages, that of the physicist and that of the student. We are indebted to the many students who shared their confusions with us, wrestled with the clarity of our translations, and offered their ideas. In particular we would like to thank Kay Campeau, Henry Cruz, and Diane Huyser. Special thanks go to Diane Huyser who very carefully read several versions of the manuscript and not only made suggestions about our translations, but suggested re-organizations that have been incorporated into the text.

We have also received unselfish assistance from many of our colleagues, Arnold Arons, Larry Gould, Denny Lee, Ken McFarlane, Jacob Pipman, Robert Swenson, and George Tuthill. These physicists spent many hours joining us in our quest for the perfect translations of topics ranging from air resistance to entropy to warped space–time. Special thanks go to Bob Weinberg, whose untiring crusade for the importance of building world views was a constant inspiration at the beginning of this project.

We received very valuable feedback from colleagues who reviewed some or all of the manuscript. These reviewers include Richard Berg, University of Maryland; Joseph Boyle, Miami-Dade Community College; James Burkhart, University of Colorado; E. H. Carlson, Michigan State University; Robert Cole, University of Southern California; Alexander K. Dickison, Seminole Community College; Ruth H. Howes, Ball State University; Philip B. James, University of Missouri–St. Louis; Stanley T. Jones, The University of Alabama; Peter Michelson, Stanford University; R. Carter Morris, Florida State University; William Mullin, University of Massachusetts; and L. C. Shepley, University of Texas. Special thanks go to Mario Iona, University of Denver, for his meticulous comments

about errors and ambiguities in the manuscript. We gave serious consideration to each of their suggestions. The final version, of course, is ours and we accept the responsibility for any errors, omissions, and confusions that might appear in this text. We would appreciate it if you would send any feedback and/or comments to us at the Department of Physics, Montana State University, Bozeman, MT, 59717.

Finally, we would like to thank the editors at Prentice-Hall who guided this project from a dream through many drafts of the manuscript to this finished book; our editor Logan Campbell, who convinced us to take on this project and provided the necessary encouragement each time we faltered, and Douglas Humphrey, who has ably replaced Logan and seen the project to completion.

NOTES ON THE FORMAT

1. Symbols for physical quantities are italicized, while units are printed in the normal type, for example, *v* for velocity and m/s for meters per second.
2. Units for physical quantities are written out in the body of each chapter so that students do not have to stop and remember what each abbreviation represents. These units are abbreviated in the Questions and Problems.
3. Vector quantities are printed as boldface (for example, **F** for force) while the size (or magnitude) of the quantity is printed in italics.
4. Important terms are printed in boldface when they are introduced. All of these terms appear in the index.
5. Each chapter is followed by a summary that briefly reviews the important concepts introduced in the chapter.
6. The Do-It-Yourself Projects are meant to be done at home with a minimum of apparatus. They have been chosen to illustrate the concepts presented in the text.
7. The Questions are meant to be answered with a minimum of, or not any, mathematics. A simple Yes or No is never a complete answer. Each answer should give the reasoning used in obtaining the answer. The more difficult questions are marked with an asterisk (*). Some of these require that several concepts be combined; others require outside consultation or reading.
8. The Problems can be answered by verbal reasoning or arithmetical manipulations. The more difficult problems are marked with an asterisk (*) and may require algebraic manipulation before numerical values are inserted. At the end of some of the Problem sections we have provided a more mathematical treatment of some topics. This treatment is useful for solving the rest of the problems.

9. There are two appendices; one discusses the metric system and the other discusses writing and reading numbers in the powers-of-ten notation.

G. F. W.
L. D. K.

Contents

O Prologue On Building a World View

Physics is the study of the material world. It is a search for an explanation of the behavior of objects in the universe. This search covers the entire range of material objects, from the smallest known particles—so small that it is meaningless to discuss what they look like, to the astronomical objects—millions of times bigger than our sun or so dense that a thimbleful of material would weigh a billion tons. The search also covers the entire span of time from the primordial fireball to the ultimate fate of the universe. Within this vast realm of space and time, the searchers have one goal: to comprehend the course of events in the whole world—to create a world view.

The phrase "world view" has a fairly elastic meaning. When we think about world views, the interpretations that come to mind stretch from the philosophic to the poetic. In physics, the world view is a shared set of ideas that represents the current explanations of how the material world operates. These include some rather common constructs, like gravity and mass, as well as strange sounding ones, like quarks and black holes.

The physics world view is a dynamic creation. Ideas are constantly being proposed. Some survive the scrutiny of the community of physicists; some do not. The inclusion of new ideas often forces the rejection of previously accepted ones. Some ideas in the world view have been so firmly accepted for such a long time that it is very difficult to discard them. The model of the atom as a miniature solar system was reluctantly given up and replaced by a mathematical model that is impossible to visualize.

Abstract ideas are intuitively difficult to accept because of the loss of physical models. There is comfort in "picturing" electrons and protons as tiny balls. Physicists who yearned for the electron to be a miniature billiard ball, however, never got their wish. Cosmologist Sir Hermann Bondi, commenting on the physics of realms beyond the range of direct human experience, said, "We should be surprised that the gas molecules behave so much like billiard balls and not surprised that electrons don't." Even with this advice, though, physicists may sometimes feel like Alice in *Through The Looking Glass* listening to the White Queen say that one should be able to "believe six impossible things before breakfast."

While some of the ideas in physics might appear to be contrary to common sense, they do in fact make sense. Things that make sense—that do not violate your intuition, or common sense—are those that fit into your past experience. Common sense is a personal world view. Like the physics world view, it is built on a large experimental base. The difference between what makes sense to you and what makes sense to a physicist is, in part, due to the different range of experience. Where your observations are limited by the range of human sensations, the physicist has instruments that bring ultrahuman sensations into consideration. Your twinkling star is the physicist's window into the universe.

So, without common sense as a guide for the acceptance of a new idea, how do physicists decide which ones to adopt? Acceptance is based on whether the idea works, how well it fits into the world view, and if it is better than the old explanations. Although the most basic criteria for accepting an idea are that it agrees with the results of past experiments and successfully predicts the outcome of future experiments, acceptance is a human activity. Because it is a human activity, it has subjective aspects. The phrases "how well it fits" and "if it is better" connote opinions. Ideas have appeal; some more than others.

If an idea is very general, if it can replace many separate ideas, it is regarded as more fundamental and thus more appealing. It is possible to construct a different explanation for each observation. For example, a scheme could be created to explain the disappearance of water from an open container and another, unrelated idea could be employed to account for the fluidity of water, and so on. An idea about the structure of liquids (not just water) that could be used to explain these phenomena and many others would be a highly valued replacement for the collection of separate ideas.

The simplicity of an idea also influences opinions about its worth. If more than one construct is proposed to explain the same phenomena and if they all predict the experimental results equally well, the most appealing idea is the simplest one. While elaborate (Rube Goldberg) constructions are cute in cartoons, they hold very little value in the building of a physics world view.

Incredible as an idea may seem initially, physicists become more and more comfortable with it the longer it remains in their world view. Most physicists are comfortable with the relativistic notions of slowed-down time and warped space; when the ideas were first introduced, however, they caused quite a stir. As more and more experimental results support an idea, it gains stature and becomes a more established part of our beliefs. But, familiar and comfortable as an idea becomes, it is still tentative. Experimental results can never prove an idea; they can only disprove an idea. If predictions are borne out, the best that can be claimed is, "So far, so good."

The above description of how a physics world view is built might seem strange, but the actual developmental processes parallel those we experienced as children. Much of our knowledge about the development of common sense is based on the work of Swiss child-psychologist Jean