INTRODUCTORY PHYSICS

THIRD EDITION

JOHN D. MAYS

Introductory Physics

A Mastery-Oriented Curriculum

Third Edition

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To all those beautiful students who have helped me understand how to be a better teacher, and how to help others do the same.

REVIEWER

This text was carefully reviewed for technical accuracy and clarity of expression by

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Any errors or ambiguities that remain are the responsibility of the author.

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I wish to express my thanks to my companion-in-arms in teaching *Introductory Physics*, Cathy Waldo. No man could have a more cheerful and encouraging team teacher than she. Her ideas and our discussions together were indispensable in working out a curriculum that is both challenging and appropriate for grade-level students, and her buoyant spirit has cheered me through many a difficult day.

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And finally, thanks to my brother, Jeffrey, for laboring with me in this writing and publishing project. I could not do this without him.

Pax Christi to all these.

Contents

Preface for Teachers

Introductory Physics is a textbook designed for students performing at grade level in mathematics. For most users of this text, this means that students take the course in ninth grade while concurrently taking Algebra 1. We strongly recommend this "physics-first" science curriculum, which places introductory physics in ninth grade. By placing physics at the beginning of the high school science curriculum, students are already familiar with basic physical concepts such as matter, energy, radiation, and heat transfer when they enter biology and chemistry.

1. A Different Textbook Philosophy

From the size of this text and the layout of its pages, it should be immediately apparent that the design philosophy represented here is significantly different from the thinking that governs science texts produced by other publishers. There are many specific differences that distinguish this text from others. Some of my comments in this Preface address these distinctive features. But there is a lot to say about our textbook philosophy, so for a full description I invite you to visit our website, novarescienceandmath.com.

Kingdom Perspective

Science and mathematics provide us with unique ways of seeing God's creative presence in the world. But bringing biblical faithfulness to science classes is not accomplished simply by folding in a few Bible verses or prayers; in fact, much more is involved. Science and math teachers should think broadly about how we fulfill Christ's mandate to love God with all our mind, how we teach our students to engage issues effectively, and how we perceive God's fingerprints in creation.

All our science texts are suffused with a robust Christian worldview that is fearlessly scientific. We reject the common rhetoric about the "faith-science debate." There can be no conflict between study of the world God made and belief in the one who made it. Contemporary science reveals much to us about the complexity, balance, and mystery in creation, and this knowledge constantly reinforces and affirms our faith.

Wonder, Integration, Mastery

This text supports the teaching model I developed over a ten-year period, described in detail in my book, *Teaching Science so that Students Learn Science.*[1] This model may be summarized in terms of three key principles—Wonder, Integration, and Mastery.

Wonder

We believe that appreciation for—and care for—the natural world begins with a sense of wonder at the exquisite complexity and balance we see everywhere in nature. In today's fast-paced world, students typically grow up without spending much time outside exploring the natural environment. Moreover, safety concerns often leave parents disinclined to allow their children to go out exploring on their own. One or two generations ago, it was common for students to spend much of their leisure time outdoors, biking, playing in the woods, exploring creeks, camping, hiking, fishing, and the like. Today, we must seek other opportunities to help our students develop a love for the natural world. As this love is culti-

1 *Teaching Science so that Students Learn Science*, revised edition, John D. Mays (2018), published by Novare Science & Math and available at novarescienceandmath.com.

vated, students are more interested in studying nature in their science classes, and they are more inclined to develop healthy attitudes toward caring for and preserving the earth and its millions of species of living creatures.

Throughout our texts, we strive to instill in students a sense of wonder and fascination with the natural world. This is not difficult, since nature is, of course, loaded with beautiful and amazing creatures, formations, and processes. It is our hope that as students pick up on our enthusiasm for the amazing world around us they will be stimulated to learn more about it, and that this knowledge will enhance their enjoyment of the natural world and lead to an increased desire to help care for the earth.

Integration

Science is not merely a collection of facts about nature and technology. Effective teaching and learning in science requires embedding several related content areas in the science curriculum—areas that are often under-represented. These include the cyclic process of scientific enquiry, basic epistemology, mathematics, scientific history, and emphasis on the use of language. Typically, science classes do not place the necessary emphasis on these areas. As a result, the student learning experience is impoverished and insipid. In this text, these crucial areas of integration are present in every chapter.

Mastery

The norm for classes in contemporary schools is what I call the *Cram-Pass-Forget cycle*, in which students cram for tests, pass them, and then forget most of what they crammed in just a few weeks. Teachers across the nation know exactly what this looks like because they see it day after day. This cycle is a waste of time for teachers and students. Instead, students should *learn*, *master*, and *retain* what they have learned. Realizing this in the classroom requires both the teacher and the students to make significant changes in the ways they approach the tasks of teaching, testing, practicing, and studying.

The mastery component of the teaching model this text supports is of key importance. Typical high school science texts are 600 or 700 pages long, or even longer. I suppose this is because the authors believe they mustn't leave anything out and that introductory courses should cover everything. But there is simply no way students can learn everything. On their part, teachers feel the obligation to "cover" what is in the text, or at least most of it, trusting that the author of the text must be a good judge of what course content for a year of science should look like. As a result, teachers often end up teaching through the text superficially, perpetuating the *Cram-Pass-Forget* cycle.

This disastrous cycle, standard operating procedure in nearly every school in our nation, has brought us to the point of total exasperation. It is a rare student in our day who masters what you teach him in a math or science class, remembers it, and can use it weeks or months down the road when it is needed. (The same is true for all subjects, not just science.) As a teacher, I consider this circumstance unacceptable. And thus the cornerstone of my work as a teacher and writer has been to develop pedagogical methods and curriculum materials that lead students *en masse* to mastery and long-term retention. I should emphasize that a teaching model centered on mastery is not just for accelerated or honors-level students. Ordinary students benefit from mastery-based instruction just as much or more. Sometimes, their lives are completely changed by the experience of mastering and remembering, and school is transformed from drudgery to the joy of effective learning.

This text is designed to support an effective, mastery-based teaching model. Over the course of some 12 or 13 years teaching ninth-grade science, I focused on developing methods that bring students to mastery and long-term retention, constantly studying and tweaking the curriculum to discover how much material students could actually master and retain in one year, and how to lead them to it. I discovered that a mastery-based teaching model requires reigning in the curriculum and narrowing the topics addressed to a small enough set that true mastery becomes possible. Most high school freshmen, including the really bright ones, cannot master a 500+ page text in one year. If mastery is the teaching goal, as it is mine, deliberate choices must be made so that the course demands remain reasonable within the framework of other course programming.

But while carving the content down to size, I also discovered that mastering and remembering a modest set of basics is vastly more powerful and satisfying than superficial coverage of a larger set of topics when many of them are half learned and most are forgotten. In fact, a large percentage of my senior physics students still remember a great deal of what they learned from me as freshmen. As a result, we can move through the senior physics course—which includes all the standard topics—at a rapid pace. In short, the methods work.

2. Teaching With This Text

Skills and Prerequisites

As you will see when you look inside, the problems in the examples and problem sets almost amount to a celebration of the basic math skills that are used ubiquitously in science. These skills include using scientific notation, performing unit conversions, using the metric prefixes, determining significant digits, and isolating variables in equations. Every one of these skills is basic and essential. Students study most of them in their pre-algebra courses. However, science classes in which the use of these skills is continuous—so that students truly master them—are few. The way to address this problem is to use these skills every day, week after week. Time and again I have brought classes of ordinary, grade-level students to true proficiency in the use of these skills.

In this text, I assume that students possess reasonable proficiency in the pre-algebra skills listed above, but teachers should expect to review these skills with their students in class. This text includes a fairly comprehensive tutorial on performing unit conversions, which most students have learned about but usually have not mastered by this point. Scientific notation is another skill that students have usually learned about but not mastered. Teachers should work with students to help them develop the mental math skills associated with adding or subtracting the powers of ten, but of particular importance is for students to know how to use the EE or EXP buttons on their calculators so that values in scientific notation can be entered into the calculator correctly. My motto in class is, if I am pushing buttons on my calculator the students are, too.

Optional Chapter Content

When I taught this course to ninth-grade, grade-level students, I taught the contents of this book and the five laboratory experiments, but without Chapters 8 (Pressure and Buoyancy) and 13 (Geometric Optics). If mastery is your goal, and I hope it is, then the other eleven chapters are plenty for grade-level freshmen to cover in a single course. My advice to teachers in similar circumstances is to skip Chapters 8 and 13.

I added these two additional chapters after discussions with schools (and some home-school parents) who have a non-vector physics course in their program for upper-level students. Grade-level juniors, for example, sometimes take such a course while concurrently enrolled in Algebra 2. These older students are capable of doing more in a year than freshmen are. Additionally, their more advanced status in mathematics means they can handle more algebra in solving problems. For these students, the extra two chapters gives them a broader exposure to basic topics in physics.

The mathematics involved in Chapters 8 and 13 is similar in difficulty to the math encountered in Chapters 5 (Momentum) and 11 (DC Circuits). For freshmen, the math in Chapters 5 and 11 is the most challenging in the text. Two chapters like this are enough for them. For older students, algebra is more familiar territory and the additional two chapters give them a solid workout in algebra along with the benefit of the additional topics.

Assignments, Homework, and the Weekly Workload

I do not recommend assigning very much homework addressing new material. Instead, I usually give students a fair amount of time to work on exercises in class. The major exception to this is the lab reports, which are completed entirely outside of class.

The reason outside assignments are kept to a minimum is that mastery requires regular review and practice. Since my goal for students is mastery, I help them achieve that goal by encouraging them to spend their study time at home rehearsing the material we covered in class to get it firmly in their memories, and working through review exercises to keep older material fresh. If they keep up with these tasks, they will spend two to three hours per week outside of class studying and rehearsing older course material. Since I do not wish for the student workload to be any higher than this, I give students time in class to work on assignments addressing new material. Diligent students complete the majority of these exercises in class. Less efficient students inevitably end up completing some of their work at home.

Memory work is a significant part of every science course and this course is no different. It is impossible to think and converse about physics unless one not only understands the concepts, but also knows the major laws, equations, conversion factors, metric prefixes, and a few physical constants by heart. This is the reason I require students to memorize specific sets of information, as indicated in the Objectives Lists found at the beginning of each chapter. General cultural and scientific literacy also requires that students have a modest amount of historical information in their heads, so I have built in requirements to this effect in the course. Parents sometimes disagree with me about this, sometimes rather strongly. But having spent a significant portion of my adult life in graduate school, 14 years as a professional in the engineering world, and two decades as an educator, I am firmly persuaded that my point of view on this is sound.

But having established the need for some memorization, I hasten to add that there is no point in having students memorize reference data such as particle masses, element densities, or information from the Periodic Table of the Elements. Instead, students need to learn how to use resources like the periodic table or data tables and whenever possible I provide these for students to use on their quizzes and exercises. As a specific case in point, I require students to know the major conversion factors for working within the metric system and others for working within the U.S. Customary System of units (which most of them have known since they were children). But the only conversion factor I require freshmen to memorize for converting between these two systems is 1 inch = 2.54 centimeters. This one factor is used a lot and has the beauty of being exact. One can also get by with this conversion factor alone, even without any of the other SI to USCS length conversion factors. Other factors for converting miles to meters or gallons to liters can always be looked up when needed.

Experiments and Experimental Error

One of the conventional calculations in high school and college physics experiments is the so-called "experimental error." Experimental error is typically defined as the difference between the predicted value (which comes from scientific theory) and the experimental value, expressed as a percentage of the predicted value, or

$$\text{experimental error} = \frac{|\text{predicted or accepted value} - \text{experimental value}|}{\text{predicted or accepted value}} \times 100\%$$

Although the term "experimental error" is widely used, it is in my view a poor choice of words. When there is a mismatch between predictions from theory and experimental results, the experiment may not be the source of the difference. Often, it is the theory that is found wanting. This is how science advances.

It is, of course, true that at the introductory and intermediate levels students are not generally engaged in research that uncovers weaknesses in scientific theories. At this level, the difference between prediction and experimental result may well be due entirely to "experimental error" arising from experimental limitations or inaccuracies. However, I prefer that students develop scientific habits of mind, and in the real world of scientific research in physics and engineering, the measurements are as accurate as the experimenters know how to make them and one does not know whether differences between mathematical prediction and experimental result are due to the mathematical model or error in the experiment.

I prefer to use the phrase *percent difference* to describe the value computed by the above equation. When quantitative results are compared to quantitative predictions or accepted values, students should compute the percent difference as

$$\text{percent difference} = \frac{|\text{predicted or accepted value} - \text{experimental value}|}{\text{predicted or accepted value}} \times 100\%$$

One more note. In the study of statistics, there is a calculation call the "percentage difference," in which the difference between two values is divided by their average. To avoid potential future confusion, you should note the distinction between the calculation we are using here and the one arising in statistics.

3. Companion Resources

There are several important companion resources for instructors and students designed to be used alongside this text. These are described below and are available from our website.

Teaching Science so that Students Learn Science

To achieve mastery with the basic math skills and all the physics content, students need to use what they learn every week. The weekly cumulative quiz regimen I use with *Introductory Physics* is a very important part of this process and is one of the hallmarks of the course. The exercises, Weekly Review Guides, "daily questions," and other activities are all oriented toward enabling students to perform well on these quizzes, which should account for the large majority of each student's grade. As I mention above, all these teaching methods are described in *Teaching Science so that Students Learn Science*. I commend this book as an essential companion volume to this text for anyone teaching the course.

Experiments Resources

Favorite Experiments for Physics and Physical Science describes in detail the background, apparatus, and practical considerations for the five experiments listed in the appendix of this volume and the other class demonstrations I use when teaching *Introductory Physics*. *Favorite Experiments* also describes all the experiments I use in my upper-level physics course. Each presentation includes illustrative photographs. The background material students need for each laboratory experiment is included in the present volume, in Appendix C. But for the full details to assure that each experiment is a success, teachers will want to avail themselves of the detailed descriptions available in *Favorite Experiments*.

For those who seek only the information for the five experiments, our small book *Experiments for Introductory Physics and ASPC* is available at significantly lower cost.

Teacher Resource CD

To facilitate using the mastery-based teaching model, the following resources are available on the resource CD:

Course Overview This document outlines all the specifics of how I have taught this course, including the cumulative weekly quiz regimen, grading rubrics, and other details.

Quiz Bank This is a set of 28 quizzes for the weekly quiz. The files are in Microsoft Word to facilitate editing.

Final Exams These are two cumulative semester exams for fall and spring. The files are in Microsoft Word to facilitate editing.

Weekly Review Guide Bank As part of the mastery-oriented nature of this course, students are given a Weekly Review Guide each week beginning with week three. The Weekly Review Guides focus on rehearsal and review of previously covered material so that it stays fresh. This set of 23 review guides is also formatted in Microsoft Word.

Course Schedule This sample lesson schedule is based on class meetings four days per week, and covers the entire text in one regular school year.

All Keys and Sample Answers This document provides example answers to all the verbal questions in the text, the quizzes, and the exams. Also included are solutions to all problems on the quizzes, semester exams, and Weekly Review Guides.

The Student Lab Report Handbook

Copies of this book should be supplied to high school freshmen so they can use the book as a resource for science lab report writing year after year throughout high school and on into college. *The Handbook* presents virtually everything students need to know in order to write excellent lab reports.

Solutions Manual to Accompany Introductory Physics

This book contains fully written solutions for every computational problem in the text. The answers for the problems are included in the present volume. But for those who would like to have full solutions handy for reference, this manual fills that need.

Complete Solutions and Answers for Introductory Physics

This resource is designed specifically for teachers and includes complete solutions and answers for every computation and question in the course. All the sample answers and keys from the Resource CD and all the solutions in the *Solutions Manual* are combined in this single volume.

4. Revisions in the Second Edition

In the second edition of *Introductory Physics*, minor editorial revisions are made throughout the text. However, teachers accustomed to the first edition should be aware that significant revisions to actual content are made to the following topics:

- Chapter 1: The explanation of how we know truth is revised and significantly expanded. Many new examples are added to illustrate the distinction between truth claims and statements that we can actually know are true. The Cycle of Scientific Enterprise is revised to include Analysis and Review steps in the cycle.
- Chapter 2: An additional step regarding checking one's work for reasonableness is added to the Universal Problem Solving Strategy. The description of the Copernican Revolution is significantly revised and expanded. In particular, Galileo's confrontation with authorities and trial is revised to reflect the nuanced roles of church authorities, Church policy, and Galileo himself.
- Chapter 4: The definition of thermal energy is revised.
- Chapter 6: The description of homogeneous mixtures and solutions is revised to reflect the fact that these are now generally regarded as different names for the same type of substance. Plasma is added to the descriptions of the basic phases of matter. Phase diagrams are added to the discussion of phase transitions. The concepts of heat of fusion and heat of vaporization are added to this discussion.
- Chapter 7: The definition of thermal energy is revised.
- Chapter 9: The explanation of standing waves and resonance is revised. The discussion of harmonics and timbre is relocated to be included in the discussion of resonance.
- Glossary: A glossary of terms has been added.
- New Appendix: Appendix E on Making Accurate Measurements is added.

5. Revisions in the Third Edition

In this third edition of *Introductory Physics*, minor editorial revisions are made throughout the text. Additionally, revisions to actual content are as follows:

- Chapter 7: A new section is added so that conduction of heat in nonmetals is treated separately from conduction of heat in metals. The role of conduction electrons in metals is discussed in some detail.
- Metric prefixes: The prefixes pico- and tera- are added to the list of metric prefixes required for memory in Table A.2.

Preface for Students

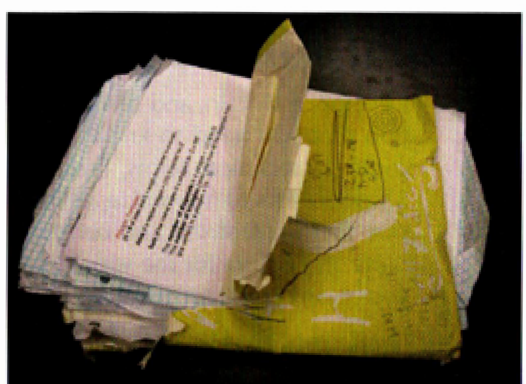
This course is designed to challenge you, while bringing you to a solid level of mastery. Physics is a challenging subject. But this course is designed so that just about anyone with ordinary scientific and mathematical abilities can understand, and *master*, all the concepts and principles presented in this book. For you to succeed in *Introductory Physics*, there are a few essential things you—the student—should bring to the table.

First, you should have a sincere desire to learn. This is not the same as liking science. Nearly everyone likes science. We are all fascinated by octopuses and lasers, explosions and rockets. But since this course is specifically designed to enable the student to learn, master, and retain core knowledge and skills, you must desire to learn. And learning takes work, as does achievement in anything. If you play on a sports team or if you play a musical instrument, you probably really like doing it. But you also know that it takes a lot of practice to get good at it. Some of this practice is painful and much of it is exhausting. But because you love your sport or your instrument, you don't mind the pain, the fatigue, and the hours spent. The same things apply to this course of study.

Which brings us to the second thing: you need to develop the discipline to study and review the way you need to, as I describe on the next page. Doing our work well is not really an option for Christians. Colossians 3:23 tells us, "Whatever you do, work heartily, as for the Lord and not for men." So I encourage you to view your studies as *the Lord's work*, something you should work at heartily for *Him*, and not something to ignore or put off. Regarding your work this way is part of being mature.

Third, you need to ask questions. Having taught courses like this one for many years, I can attest that students who are engaged in learning ask questions. If you never ask any, it is a sign to your teacher that there is trouble ahead for you. When reviewing new topics questions always arise. Ask them! When working through problem sets, there will be times when you do not understand something. Ask your instructor about it. This is an important two-way street. If you are engaged, questions will arise. You will get the answers you need by asking your instructor. And when you do, the instructor knows that since you are asking questions you are engaged with the material. The instructor also knows from your questions how well you are progressing, and this will enable him or her to bring things into the classroom that will help you and other students along.

Fourth, you need to be organized! If you are studying well, your notebook will be well organized. If it is not well organized, it is a sign that you are not doing the work that is required. When students claim that they are studying hard while their notebooks are messy and disorganized like the one in the photo (an actual student's notebook), it is clear that their claims are exaggerated. Effective study requires you to have separate sections in your course binder for notes, quizzes, review guides, homework papers, lab reports, and practice problems. These papers should all be filed in your binder, in order, so you can easily find and use them as you review. Unlike previous courses you may have had, this course is designed for *mastery*. There is a lot of review involved because we want you to remember the things you learn, rather than forgetting them a few weeks after completing the chapter.



Not a good sign.

Finally, you must apply yourself to all the exercises. In addition to the regular exercises assigned in each chapter, you will be given a Weekly Review Guide containing a list of exercises and review activities. The review guides tell you to make and rehearse flash cards, work problems, recite memory work, and other tasks. You must be diligent about accomplishing these tasks if you desire to succeed in *Introductory Physics*. I have outlined the essential components for a complete study strategy in the box below.

For years, students have said that *Introductory Physics* was one of the classes in which they learned the most. If you do the work assigned, including the review exercises, you will indeed learn a lot about this fascinating world God made. And you will have a great year, too!

A Solid Study Strategy

Your grade in *Introductory Physics* will be very strongly based on your performance on the weekly quizzes that occur throughout the year. These quizzes are cumulative, which means that once new material is covered in class you are responsible for it on quizzes all year long.

To be prepared for the weekly cumulative quizzes, you should establish a weekly study regimen encompassing each of the tasks listed below. You should spread out your review work so that you spend time with the material at least two or three separate days each week. Most students find that an hour spent two to three times per week is adequate for solid performance in the course.

These are the documents you must pay attention to and use in your weekly studies:

- Chapter Objectives Lists (11 total for the year, not counting the optional chapters, 8 and 13)
- Scientists List (see Appendix D)
- Conversion Factors and Constants (see Appendix A)
- Weekly Review Guides

1. Study the Objectives List for each new chapter carefully. Make it your policy that you will be able to do everything on the list (that is, for the objectives that have been covered so far in class) before quiz day each week.
2. Look over Objectives Lists from previous chapters regularly. Identify any item that you cannot do or cannot remember how to do and follow up on it.
3. Develop, maintain, and practice flash cards for each major category of information that you need to know. I recommend these four separate stacks of flash cards: 1) technical terms, laws, and equations; 2) scientists and experiments; 3) special lists to memorize (as indicated by the Objectives Lists); and 4) conversion factors, prefixes, and constants. Also, on cards for equations, indicate the units of measure for the variables involved and make saying those units part of your flash card practice routine.
4. Read every chapter in this text at least once, and preferably twice. Ideally, every time your instructor covers new material you should read the sections in this book corresponding to that material within 24 hours.

5. Go through the exercises described in the Weekly Review Guide every week. Work each of the four review computations. The Review Guide prompts you to rehearse your flash cards, review older topics, and so on. Take the Weekly Review Guide seriously and do what it says.
6. Raise questions in class as often as you can. Asking questions and interacting with the instructor and the rest of the class is an effective way to help your brain engage, focus, and remember.
7. Go back and read the chapters in this book again when you are a month or two down the road. You will be amazed at how much easier it is to remember things when you have reread a chapter. (Besides, reading is more fun than rehearsing flash cards.)
8. When you are working on exercises involving computations, check your answers against the answer key. Every time you get an incorrect answer, dig in and stay with the problem until you identify your mistake and obtain the correct answer. If you can't figure out a problem after 10 or 15 minutes, raise the question in class.
9. Every time you lose significant points on a quiz, follow up and fill in the gaps in your learning. If you didn't understand something, raise the question with your instructor. If you forgot something, rehearse it more thoroughly until you have it down. If you failed to commit something to memory or didn't have it in your flash cards, then add it to the cards and commit it to memory. If you were not proficient enough at one or more of the computations, look up some similar problems from the exercises or from previous quizzes and practice them thoroughly. Always follow up before the next quiz. Remember, the quizzes are cumulative and the same questions come up again and again.

If you study for the course according to this study plan, you cannot help but be successful in the course and you will find that very satisfying. You will not only know a lot about physics, but you will have the satisfaction that comes from doing a job well. (By the way, you should apply this same strategy to your other classes. It works there, too!)

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CHAPTER 1

The Nature of Scientific Knowledge

Theory → Hypothesis → Experiment

In 1915, Albert Einstein produced his general theory of relativity. In 1917, Einstein announced an amazing new hypothesis: according to the theory, light traveling through space bends as it passes near a star. In 1919, this hypothesis was confirmed by teams under the leadership of Sir Arthur Eddington, using photographs taken of stars positioned near the sun in the sky during a solar eclipse.

The image above is a positive created from one of Eddington's negatives.

OBJECTIVES

After studying this chapter and completing the exercises, students will be able to do each of the following tasks, using supporting terms and principles as necessary:

1. Define science, theory, hypothesis, and scientific fact.
2. Explain the difference between truth and scientific facts and describe how we obtain knowledge of each.
3. Describe the difference between General Revelation and Special Revelation and relate these to our definition of truth.
4. Describe the "Cycle of Scientific Enterprise," including the relationships between facts, theories, hypotheses, and experiments.
5. Explain what a theory is and describe the two main characteristics of a theory.
6. Explain what is meant by the statement, "a theory is a model."
7. Explain the role and importance of theories in scientific research.
8. State and describe the steps of the "scientific method."
9. Define explanatory, response, and lurking variables in the context of an experiment.
10. Explain why experiments are designed to test only one explanatory variable at a time. Use the procedures the class followed in the Pendulum Experiment as a case in point.
11. Explain the purpose of the control group in an experiment.
12. Describe the possible implications of a negative experimental result. In other words, if the hypothesis is not confirmed, explain what this might imply about the experiment, the hypothesis, or the theory itself.

1.1 Modeling Knowledge

1.1.1 Kinds of Knowledge

There are many different kinds of knowledge. One kind of knowledge is *truth*. As Christians, we are very concerned about truth because of its close relation to knowledge revealed to us by God. The facts and theories of science constitute a different kind of knowledge, and as students of the natural sciences we are also concerned about these.

Some people handle the distinction between the truths of the faith and scientific knowledge by referring to religious teachings as one kind of truth and scientific teaching as a different kind of truth. The problem here is that there are not different kinds of truth. There is only *one* truth, but there *are* different kinds of knowledge. Truth is one kind of knowledge, and scientific knowledge is a different kind of knowledge.

We are going to unpack this further over the next few pages, but here is a taste of where we are going. Scientific knowledge is not static. It is always changing as new discoveries are made. On the other hand, the core teachings of Christianity do not change. They are always true. We know this because God reveals them to us in his Word, which is true. This difference between scientific knowledge and knowledge from Scripture indicates to us that the knowledge we have from the Scriptures is a different kind of knowledge than what we learn from scientific investigations.

I have developed a model of knowledge that emphasizes the differences between what God reveals to us and what scientific investigations teach us. This model is not perfect (no model is), nor is it exhaustive, but it is very useful, as all good models are. Our main goal in the next few sections is to develop this model of knowledge. The material in this chapter is crucial if you wish to have a proper understanding of what science is all about.

To understand science correctly, we need to understand what we mean by scientific knowledge. Unfortunately, there is much confusion among non-scientists about the nature of scientific knowledge and this confusion often leads to misunderstandings when we talk about scientific findings and scientific claims. This is nothing new. Misconceptions about scientific claims have plagued public discourse for thousands of years and continue to do so to this day. This confusion is a severe problem, one much written about within the scientific community in recent years.

To clear the air on this issue, it is necessary to examine what we mean by the term *truth*, as well as the different ways we discover truth. Then we must discuss the specific characteristics of scientific knowledge, including the key scientific terms *fact*, *theory*, and *hypothesis*.

1.1.2 What is Truth and How Do We Know It?

Epistemology, one of the major branches of philosophy, is the study of what we can know and how we know it. Both philosophers and theologians claim to have important insights on the issue of knowing truth, and because of the roles science and religion have played in our culture over the centuries, we need to look at what both philosophers and theologians have to say. The issue we need to treat briefly here is captured in this question: What is truth and how do we know it? In other words, what do we mean when we say something is *true*? And if we can agree on a definition for truth, how can we *know* whether something is true?

These are really complex questions, and philosophers and theologians have been working on them for thousands of years. But a few simple principles will be adequate for our purpose.

As for what truth is, my simple but practical definition is this:

Truth is the way things really are.

Whatever reality is like, that is the truth. If there *really* is life on other planets, then it is true to say, "There is life on other planets." If you live in Poughkeepsie, then when you say, "I live in Poughkeepsie" you are speaking the truth.

The harder question is: How do we know the truth? According to most philosophers, there are two ways that we can know truth, and these involve either our senses or our use of reason. First, truths that are obvious to us just by looking around are said to be *evident*. It is evident that birds can fly. No proof is needed. So the proposition, "Birds can fly," conveys truth. Similarly, it is evident that humans can read books and that birds cannot. Of course, when we speak of people knowing truth this way we are referring to people whose perceptive faculties are functioning normally.

The second way philosophers say we can know truth is through the valid use of logic. Logical conclusions are typically derived from a sequence of logical statements called a *syllogism*, in which two or more statements (called *premises*) lead to a conclusion. For example, if we begin with the premises, "All men are mortal," and, "Socrates was a man," then it is a valid conclusion to state, "Socrates was mortal." The truth of the conclusion of a logical syllogism definitely depends on the truth of the premises. The truth of the conclusion also depends on the syllogism having a valid structure. Some logical structures are not logically valid. (These invalid structures are called *logical fallacies.*) If the premises are true and the structure is valid, then the conclusion must be true.

So the philosophers provide us with two ways of knowing truth that most people agree upon—truths can be evident (according to our senses) or they can be proven (by valid use of reason from true premises).

Believers in some faith traditions—including Christianity—argue for a crucial third possibility for knowing truth, which is by revelation from supernatural agents such as God or angels. Jesus said, "I am the way, and the truth, and the life" (John 14:6). As Christians, we believe that Jesus was "God with us" and that all he said and did were revelations of truth to us from God the Father. Further, we believe that the Bible is inspired by God and reveals truth to us. We return to the ways God reveals truth to us at the end of this section.

Obviously, not everyone accepts the possibility of knowing truth by revelation. Specifically, those who do not believe in God do not accept the possibility of revelations from God. Additionally, there are some who accept the existence of a transcendent power or being, but do not accept the possibility of revelations of truth from that power. So this third way of knowing truth is embraced by many people, but certainly not by everyone.

Few people would deny that knowing truth is important. This is why we started our study by briefly exploring what truth is. But this is a book about science, and we need now to move to addressing a different question: what does *science* have to do with truth? The question is not as simple as it seems, as evidenced by the continuous disputes between religious and scientific communities stretching back over the past 700 years. To get at the relationship between science and truth, we first look at the relationship between propositions and truth claims.

1.1.3 Propositions and Truth Claims

Not all that passes as valid knowledge can be regarded as *true*, which I defined in the previous section as "the way things really are." In many circumstances—maybe most—we do not actually *know* the way things really are. People do, of course, often use propositions or statements with the intention of conveying truth. But with other kinds of statements, people intend to convey something else.

Let's unpack this with a few example statements. Consider the following propositions:

1. I have two arms.
2. My wife and I have three children.
3. I worked out at the gym last week.
4. My car is at the repair shop.
5. Texas gained its independence from Mexico in 1836.
6. Atoms are composed of three fundamental particles—protons, neutrons, and electrons.
7. God made the world.

Among these seven statements are actually three different types of claims. From the discussion in the previous section you may already be able to spot two of them. But some of these statements do not fit into any of the categories we explored in our discussion of truth. We can discover some important aspects about these claims be examining them one by one. So suppose for a moment that I, the writer, am the person asserting each of these statements as we examine the nature of the claim in each case.

I have two arms. This is true. I do have two arms, as is evident to everyone who sees me.

My wife and I have three children. This is true. To me it is just as evident as my two arms. I might also point out that it is true regardless of whether other people believe me when I say it. (Of course, someone could claim that I am delusional, but let's just keep it simple here and assume I am in normal possession of my faculties.) This bit about the statement being true regardless of others' acceptance of it comes up because of a slight difference here between the statement about children and the statement about arms. Anyone who looks at me will accept the truth that I have two arms. It will be evident, that is, obvious, to them. But the truth about my children is only really evident to a few people (my wife and I, and perhaps a few doctors and close family members). Nevertheless, the statement is true.

I worked out at the gym last week. This is also true; I did work out last week. The statement is evident to me because I clearly remember going there. Of course, people besides myself must depend on me to know it because they cannot know it directly for themselves unless they saw me there. Note that I cannot prove it is true. I can produce evidence, if needed, but the statement cannot be proven without appealing to premises that may or may not be true. Still, the statement is true.

My car is at the repair shop. Here is a statement that we cannot regard as a truth claim. It is merely a statement about where I understand my car to be at present, based on where I left it this morning and what the people at the shop told me they were going to do with it. For all I know, they may have taken my car joy riding and presently it may be flying along the back roads of the Texas hill country. I *can* say that the statement is correct so far as I know.

Texas gained its independence from Mexico in 1836. We Texans were all taught this in school and we believe it to be correct, but as with the previous statement we must stop short of calling this a truth claim. It is certainly a *historical fact*, based on a lot of historical evidence. The statement is correct so far as we know. But it is possible there is more to that story than we know at present (or will ever know) and none of those now living were there.

Atoms are composed of three fundamental particles—protons, neutrons, and electrons. This statement is, of course, a scientific fact. But like the previous two statements, this statement is not—surprise!—a truth claim. We simply do not know the truth about atoms. The truth about atoms is clearly not evident to our senses. We cannot guarantee the truth of any premises we might use to construct a logical proof about the insides of atoms, so proof is not able to lead us to the truth. And so far as I know, there are no supernatural agents who have revealed to us anything about atoms. So we have no access to knowing how atoms really are. What we do have are the data from many experiments, which may or may not tell the whole story. Atoms may have other components we don't know about yet. The best we can say about this statement is that *it is correct so far as we know* (that is, so far as the scientific community knows).

God made the world. This statement clearly is a truth claim, and we Christians joyfully believe it. But other people disagree on whether the statement is true. I include this example here because we soon see what happens when scientific claims and religious truth claims get confused. I hope you are a Christian, but regardless of whether you are, the issue is important. We all need to learn to speak correctly about the different claims people make.

To summarize this section, some statements we make are evidently or obviously true. But for many statements, we must recognize that we don't know if they actually are true. The best we can say about these kinds of statements—and scientific facts are like this—is that they are correct so far as we know. Finally, there are metaphysical or religious statements about which people disagree; some claim they are true, some deny the same, and some say there is no way to know.

1.1.4 Truth and Scientific Claims

Let's think a bit further about the truth of reality, both natural and supernatural. Most people agree that regardless of what different people think about God and nature, there is some actual truth or *reality* about nature and the supernatural. Regarding nature, there is some full reality about the way, say, atoms are structured, regardless of whether we currently understand that structure correctly. So far as we know, this reality does not shift or change from day to day, at least not since the early history of the universe. So the reality about atoms—the truth about atoms—does not change.

And regarding the supernatural, there is some reality about the supernatural realm, regardless of whether anyone knows what that is. Whatever these realities are, they are *truths*, and these truths do not change either.

Now, I have observed over the years that since (roughly) the beginning of the 20th century, careful scientists do not refer to scientific claims as truth claims. They do not profess to knowing the ultimate truth about how nature *really* is. For example, Niels Bohr, one of the great physicists of the 20th century, said, "It is wrong to think that the task of physics is to find out how nature *is*. Physics concerns what we can *say* about nature." Scientific claims are understood to be statements about *our best understanding* of the way things are. Most scientists believe that over time our scientific theories get closer and closer to the truth of the way things really are. But when they are speaking carefully, scientists do not claim that our present understanding of this or that is the truth about this or that.

1.1.5 Truth vs. Facts

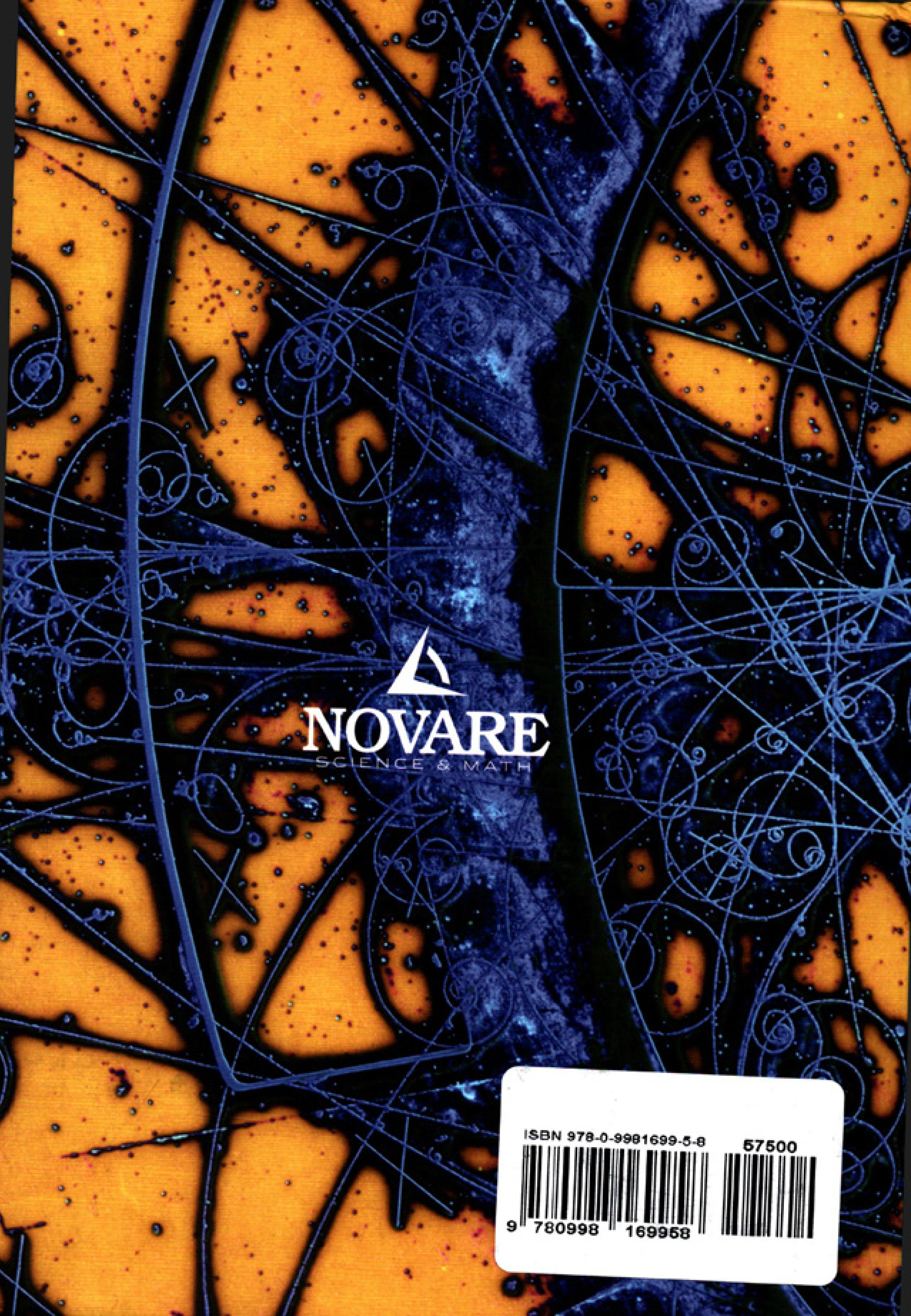
Whatever the truth is about the way things are, that truth is presumably absolute and unchanging. If there is a God, then that's the way it is, period. And if matter is made of atoms as we think it is, then that is the truth about matter and it is always the truth. But what we call scientific facts, by their very nature, are not like this. Facts are subject to change, and sometimes do, as new information comes becomes known through ongoing scientific research. Our definitions for truth and for scientific facts need to take this difference into account. As we have seen, truth is the way things really are. By contrast, here is a definition for *scientific facts*:

A scientific fact is a proposition that is supported by a great deal of evidence.

Scientific facts are discovered by observation and experiment, and by making inferences from what we observe or from the results of our experiments.

A scientific fact is *correct so far as we know*, but can change as new information becomes known.

So facts can change. Scientists do not put them forward as truth claims, but as propositions that are correct so far as we know. In other words, scientific facts are *provisional*. They are always subject to revision in the future. As scientists make new scientific discoveries,



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