Chances are you are taking this course in physics because someone told you to take it, and it may not be clear to you *why* you should be taking it. One good reason for taking a physics course is that, first and foremost, physics provides a fundamental understanding of the world. Furthermore, whether you are majoring in psychology, engineering, biology, physics, or something else, this course offers you an opportunity to sharpen your reasoning skills. Knowing physics means becoming a better problem solver (and I mean *real* problems, not textbook problems that have already been solved), and becoming a better problem solver is empowering: It allows you to step into unknown territory with more confidence. Before we embark on this exciting journey, let's map out the territory we are going to explore so that you know where we are going.

1.1 The scientific method

Physics, from the Greek word for "nature," is commonly defined as the study of matter and motion. Physics is about discovering the wonderfully simple unifying patterns that underlie absolutely everything that happens around us, from the scale of subatomic particles, to the microscopic world of DNA molecules and cells, to the cosmic scale of stars, galaxies, and planets. Physics deals with atoms and molecules; gases, solids, and liquids; everyday objects, and black holes. Physics explores motion, light, and sound; the creation and annihilation of matter; evaporation and melting; electricity and magnetism. Physics is all around you: in the Sun that provides your daylight, in the structure of your bones, in your computer, in the motion of a ball you throw. In a sense, then, physics is the study of all there is in the universe. Indeed, biology, engineering, chemistry, astronomy, geology, and so many other disciplines you might name all use the principles of physics.

The many remarkable scientific accomplishments of ancient civilizations that survive to this day testify to the fact that curiosity about the world is part of human nature. Physics evolved from *natural philosophy*—a body of knowledge accumulated in ancient times in an attempt to explain the behavior of the universe through philosophical speculation—and became a distinct discipline during the scientific revolution that began in the 16th century. One of the main changes that occurred in that century was the development of the **scientific method,** an iterative process for going from observations to validated theories.

In its simplest form, the scientific method works as follows (Figure 1.1): A researcher makes a number of observations concerning either something happening in the natural world (a volcano erupting, for instance) or something happening during a laboratory experiment (a dropped brick and a dropped Styrofoam peanut travel to the floor at different speeds). These observations then lead the researcher to formulate a **hypothesis,** which is a tentative explanation of the observed phenomenon. The hypothesis is used to predict the outcome of some related natural occurrence (how a similarly shaped mountain near the erupting volcano will behave) or related laboratory experiment (what happens when a book and a sheet of paper are dropped at the same time). If the predictions prove inaccurate, the hypothesis must be modified. If the predictions prove accurate in test after test, the hypothesis is elevated to the status of either a **law** or a **theory.**

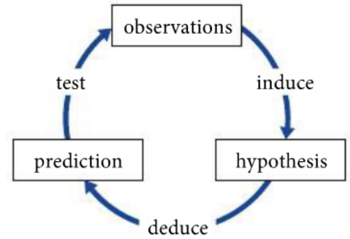


Figure 1.1 The scientific method is an iterative process in which a hypothesis, which is inferred from observations, is used to make a prediction, which is then tested by making new observations.

A law tells us *what* happens under certain circumstances. Laws are usually expressed in the form of relationships between observable quantities. A theory tells us *why* something happens and explains phenomena in terms of more basic processes and relationships. A scientific theory is not a mere conjecture or speculation. It is a thoroughly tested explanation of a natural phenomenon, one that is capable of making predictions that can be verified by experiment. The constant testing and retesting are what make the scientific method such a powerful tool for investigating the universe: The results obtained must be repeatable and verifiable by others.

Exercise 1.1 Hypothesis or not?

Which of the following statements are hypotheses? (*a*) Heavier objects fall to Earth faster than lighter ones. (*b*) The planet Mars is inhabited by invisible beings that are able to elude any type of observation. (*c*) Distant planets harbor forms of life. (*d*) Handling toads causes warts.

SOLUTION (*a*), (*c*), and (*d*). A hypothesis must be experimentally verifiable. (*a*) I can verify this statement by dropping a heavy object and a lighter one at the same instant and observing which one hits the ground first. (*b*) This statement asserts that the beings on Mars cannot be observed, which precludes any experimental verification and means this statement is not a valid hypothesis. (*c*) Although we humans currently have no means of exploring or closely observing distant planets, the statement is in principle testable. (*d*) Even though we know this statement is false, it *is* verifiable and therefore is a hypothesis.

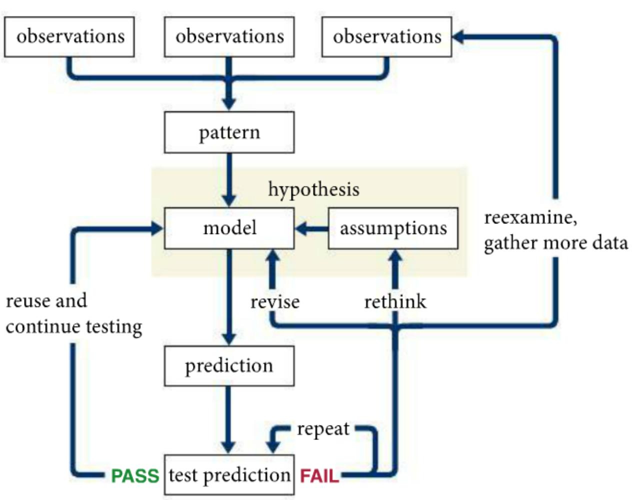
Because of the constant reevaluation demanded by the scientific method, science is not a stale collection of facts but rather a living and changing body of knowledge. More important, any theory or law *always* remains tentative, and the testing never ends. In other words, it is not possible to prove any scientific theory or law to be absolutely true (or even absolutely false). Thus the material you will learn in this book does not represent some "ultimate truth"—it is true only to the extent that it has not been proved wrong.

A case in point is *classical mechanics,* a theory developed in the 17th century to describe the motion of everyday objects (and the subject of most of this book). Although this theory produces accurate results for most everyday phenomena, from balls thrown in the air to satellites orbiting Earth, observations made during the last hundred years have revealed that under certain circumstances, significant deviations from this theory occur. It is now clear that classical mechanics is applicable for only a limited (albeit important) range of phenomena, and new branches of physics—*quantum mechanics* and the theory of *special relativity* among them—are needed to describe the phenomena that fall outside the range of classical mechanics.

The formulation of a hypothesis almost always involves developing a **model,** which is a simplified conceptual representation of some phenomenon. You don't have to be trained as a scientist to develop models. Everyone develops mental models of how people behave, how events unfold, and how things work. Without such models, we would not be able to understand our experiences, decide what actions to take, or handle unexpected experiences. Examples of models we use in everyday life are that door handles and door hinges are on opposite sides of doors and that the + button on a TV remote increases the volume or the channel number. In everyday life, we base our models on whatever knowledge we have, real or imagined, complete or incomplete. In science we must build models based on careful observation and determine ways to fill in any missing information.

Let's look at the iterative process of developing models and hypotheses in physics, with an eye toward determining what skills are needed and what pitfalls are to be avoided (**Figure 1.2**). Developing a scientific hypothesis often begins

Figure 1.2 Iterative process for developing a scientific hypothesis.



with recognizing patterns in a series of observations. Sometimes these observations are direct, but sometimes we must settle for indirect observations. (We cannot directly observe the nucleus of an atom, for instance, but a physicist can describe the structure of the nucleus and its behavior with great certainty and accuracy.) As Figure 1.2 indicates, the patterns that emerge from our observations must often be combined with simplifying assumptions to build a model. The combination of model and assumptions is what constitutes a hypothesis.

It may seem like a shaky proposition to build a hypothesis on assumptions that are accepted without proof, but making these assumptions—*consciously*—is a crucial step in making sense of the universe. All that is required is that, when formulating a hypothesis, we must be aware of these assumptions and be ready to revise or drop them if the predictions of our hypothesis are not validated. We should, in particular, watch out for what are called *hidden assumptions*—assumptions we make without being aware of them. As an example, try answering the following question. (Turn to the final section of the *Principles* volume, "Solutions to checkpoints," for the answer.)

1.1 I have two coins in my pocket, together worth 30 cents. If one of them is not a nickel, what coins are they?

Advertising agencies and magicians are masters at making us fall into the trap of hidden assumptions. Imagine a radio commercial for a new drug in which someone says, "Baroxan lowered my blood pressure tremendously." If you think that sounds good, you have made a number of assumptions without being aware of them—in other words, hidden assumptions. Who says, for instance, that lowering blood pressure "tremendously" is a good thing (dead people have tremendously low blood pressure) or that the speaker's blood pressure was too high to begin with?

Magic, too, involves hidden assumptions. The trick in some magic acts is to make you assume that something happens, often by planting a false assumption in your mind. A magician might ask, "How did I move the ball from here to there?" while in reality he is using two balls. I won't knowingly put false assumptions into *your* mind in this book, but on occasion you and I (or you and your instructor) may unknowingly make different assumptions during a given discussion, a situation that unavoidably leads to confusion and misunderstanding. Therefore it is important that we carefully analyze our thinking and watch for the assumptions that we build into our models.

If the prediction of a hypothesis fails to agree with observations made to test the hypothesis, there are several ways to address the discrepancy. One way is to rerun the test to see if it is reproducible. If the test keeps producing the same result, it becomes necessary to revise the hypothesis, rethink the assumptions that went into it, or reexamine the original observations that led to the hypothesis.

Exercise 1.2 Dead music player

A battery-operated portable music player fails to play when it is turned on. Develop a hypothesis explaining why it fails to play, and then make a prediction that permits you to test your hypothesis. Describe two possible outcomes of the test and what you conclude from the outcomes. (*Think* before you peek at the answer below.)

SOLUTION There are many reasons the player might not turn on. Here is one example. Hypothesis: The batteries are dead. Prediction: If I replace the batteries with new ones, the player should work. Possible outcomes: (1) The player works once the new batteries are installed, which means the hypothesis is supported; (2) the player doesn't work after the new batteries are installed, which means the hypothesis is not supported and must be either modified or discarded.

1.2 In Exercise 1.2, each of the conclusions drawn from the two possible outcomes contains a hidden assumption. What are the hidden assumptions?

The development of a scientific hypothesis is often more complicated than suggested by Figures 1.1 and 1.2. Hypotheses do not always start with observations; some are developed from incomplete information, vague ideas, assumptions, or even complete guesses. The refining process also has its limits. Each refinement adds complexity, and at some point the complexity outweighs the benefit of the increased accuracy. Because we like to think that the universe has an underlying simplicity, it might be better to scrap the hypothesis and start anew.

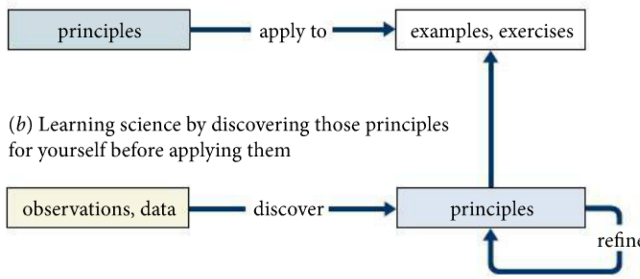
Figure 1.2 gives an idea of the skills that are useful in doing science: interpreting observations, recognizing patterns, making and recognizing assumptions, thinking logically, developing models, and using models to make predictions. It should not come as any surprise to you that many of these skills are useful in just about any context. Learning physics allows you to sharpen these skills in a very rigorous way. So, whether you become a financial analyst, a doctor, an engineer, or a research scientist (to name just a few possibilities), there is a good reason to take physics.

Figure 1.1 also shows that doing science—and physics in particular—involves two types of reasoning: *inductive*, which is arguing from the specific to the general, and *deductive*, arguing from the general to the specific. The most creative part of doing physics involves inductive reasoning, and this fact sheds light on how you might want to learn physics. One way, which is neither very useful nor very satisfying, is for me to simply tell you all the general principles physicists presently agree on and then for you to apply those principles in examples and exercises (**Figure 1.3*a***). This approach involves deductive reasoning only and robs you of the opportunity to learn the skill that is the most likely to benefit your career: discovering underlying patterns. Another way is for me to present you with data and observations and make you part of the discovery and refinement of the physics principles (Figure 1.3*b*). This approach

Figure 1.3

(*a*) Learning science by applying established principles

(*b*) Learning science by discovering those principles for yourself before applying them



is more time-consuming, and sometimes you may wonder why I'm not just *telling* you the final outcome. The reason is that discovery and refinement are at the heart of doing physics!

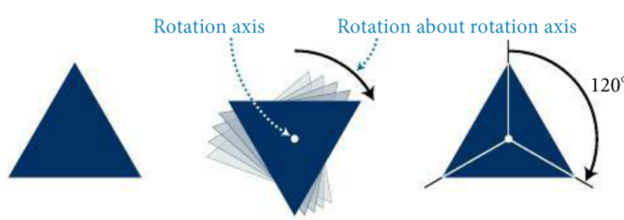
1.3 After reading this section, reflect on your goals for this course. Write down what you would like to accomplish and why you would like to accomplish this. Once you have done that, turn to the final section of the *Principles* volume, "Solutions to checkpoints," and compare what you have written with what I wrote.

1.2 Symmetry

One of the basic requirements of any law of the universe involves what physicists call *symmetry*, a concept often associated with order, beauty, and harmony. We can define **symmetry** as follows: An object exhibits symmetry when certain operations can be performed on it without changing its appearance. Consider the equilateral triangle in **Figure 1.4*a***. If you close your eyes and someone rotates the triangle by 120° while you have your eyes closed, the triangle appears

Figure 1.4

(*a*) Rotational symmetry: Rotating an equilateral triangle by 120° doesn't change how it looks



(*b*) Reflection symmetry: Across each reflection axis (labeled R), two sides of the triangle are mirror images of each other