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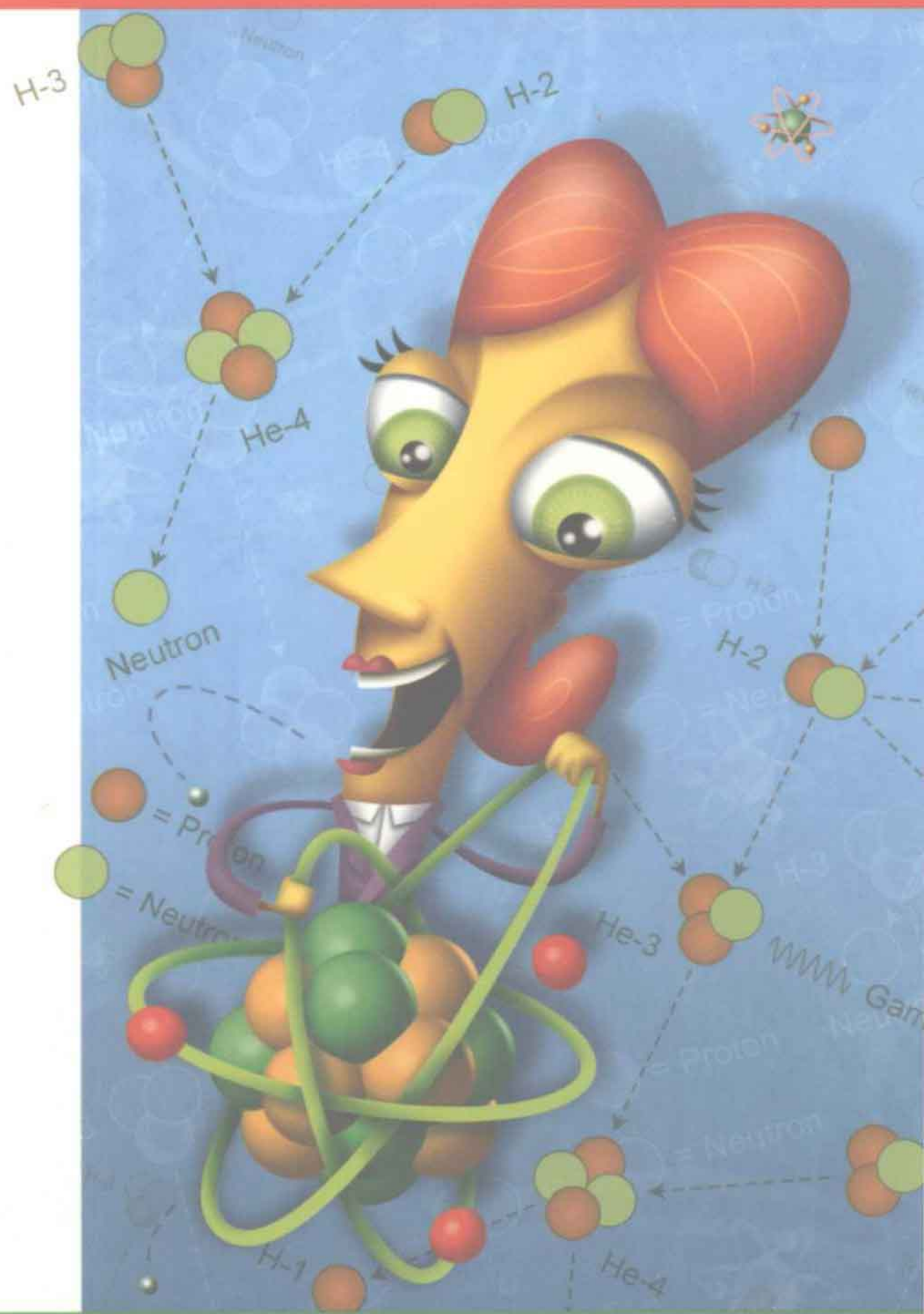
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# **Advanced Physics Demystified**

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# **Advanced Physics Demystified**



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*To Samuel, Tim, and Tony*



# ABOUT THE AUTHOR

**Stan Gibilisco** is one of McGraw-Hill's most prolific and popular authors. His clear, reader-friendly writing style makes his books accessible to a wide audience, and his experience as an electronics engineer, researcher, and mathematician makes him an ideal editor for reference books and tutorials. Stan has authored several titles for the McGraw-Hill *Demystified* library of home-schooling and self-teaching volumes, along with more than 30 other books and dozens of magazine articles. His work has been published in several languages. *Booklist* named his *McGraw-Hill Encyclopedia of Personal Computing* one of the "Best References of 1996," and named his *Encyclopedia of Electronics* one of the "Best References of the 1980s."

# PREFACE

This book is for people who want to refresh or improve their knowledge of physics. The course can be used for self-teaching or as a supplement in a classroom, tutored, or home-schooling environment.

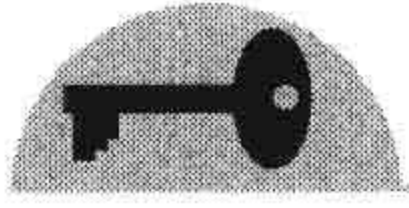
This course builds on material covered in *Physics Demystified* and is meant to serve as a continuation of that course. For that reason, I recommend that you study *Physics Demystified* before you start here. This book covers more exotic branches of physics, goes into greater depth, is more mathematical, and is written at the level of an honors physics curriculum for high-school seniors. Standard school prerequisites to this course include high-school algebra, geometry, trigonometry, first-year calculus, and first-year physics.

For those of you who want a solid mastery of math as it applies to physics, the McGraw-Hill *Demystified* Series offers several mathematics books. If you are planning to take a physics exam for college entrance, I encourage you to study as many different exam-preparation guides as you can find. You'll get some "cross-training" that way, you'll see concepts from various perspectives, and you'll be exposed to most of the notational variants that scientists and engineers use.

As you go through each chapter, you'll find practice problems with worked-out answers. Each chapter ends with a multiple-choice quiz. You may refer to the text when taking these quizzes. Because the quizzes are "open-book," some of the questions are rather difficult, but one of the choices is always "best." (I try to avoid writing trick questions.) When you're done with the quiz at the end of a particular chapter, give your list of answers to a friend. Have the friend tell you your score, but not which questions you got wrong. The answers are listed in the back of the book. Stick with a chapter until you get most, and preferably all, of the quiz answers correct.

The book concludes with a multiple-choice final exam that contains questions drawn uniformly from all the chapters. It is a "closed-book" test. Don't look back into the chapters when taking it. A satisfactory score is at least three-quarters of the





answers correct. But I suggest you shoot for 90 percent! With the final exam, as with the quizzes, have a friend tell you your score without letting you know which questions you missed. That way, you won't be likely to subconsciously memorize the answers. The questions are similar in format to those you'll encounter in standardized tests.

Suggestions for future editions are welcome.

Stan Gibilisco

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I extend thanks to my nephew Tim Boutelle, a student at the University of Chicago. He spent many hours helping me proofread the manuscript, and he offered insights and suggestions from the point of view of the intended audience.



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# CHAPTER 1



## Linear Motion and Plane Trajectories

Motion can be defined in terms of *vectors*, which are quantities having independent magnitude and direction. In *linear motion*, a vector can have any possible magnitude, but only the two directions defined by a specific, fixed straight line. A *plane trajectory* is a function of the position of an object in two dimensions with respect to time. It can be defined in terms of two independent *component vectors* that both lie in the same *Euclidean* (flat) plane, but not along the same straight line.

### Time

*Time* is a dimension through which the physical world appears to change or evolve. It can be represented by itself as a *time line*, or as an axis in a coordinate system along with spatial dimensions. Time makes two events distinguishable from each other when they occur at the same point in space. In mathematical





equations, time is treated as a *scalar* quantity, symbolized by the lowercase italic letter  $t$ . A scalar can vary only in terms of its size or scale. In some scientific disciplines, time can possess the property of direction such as forward/backward along a line or even orientation in multi-dimensional spaces, but we won't get into that.

The standard unit of time is the *second*, symbolized by the lowercase letter  $s$ . The second was originally defined as  $1/60$  of a *minute*, which is  $1/60$  of an *hour*, which is  $1/24$  of a *mean solar day*. A second was therefore considered to be  $1/86,400$  or  $1.15741 \times 10^{-5}$  of a mean solar day. That's still a fair definition, but it's problematic because the mean solar day is gradually getting longer! Nowadays the second is defined as the time required for the radiated wave corresponding to the transition between the two hyperfine levels of the ground state of the cesium-135 atom to go through  $9.19263 \times 10^9$  cycles. We don't need to be concerned with the precise meaning of the jargon here, but it's worthwhile to know that the wave oscillations produced by certain atoms make excellent universal time standards.

## Displacement

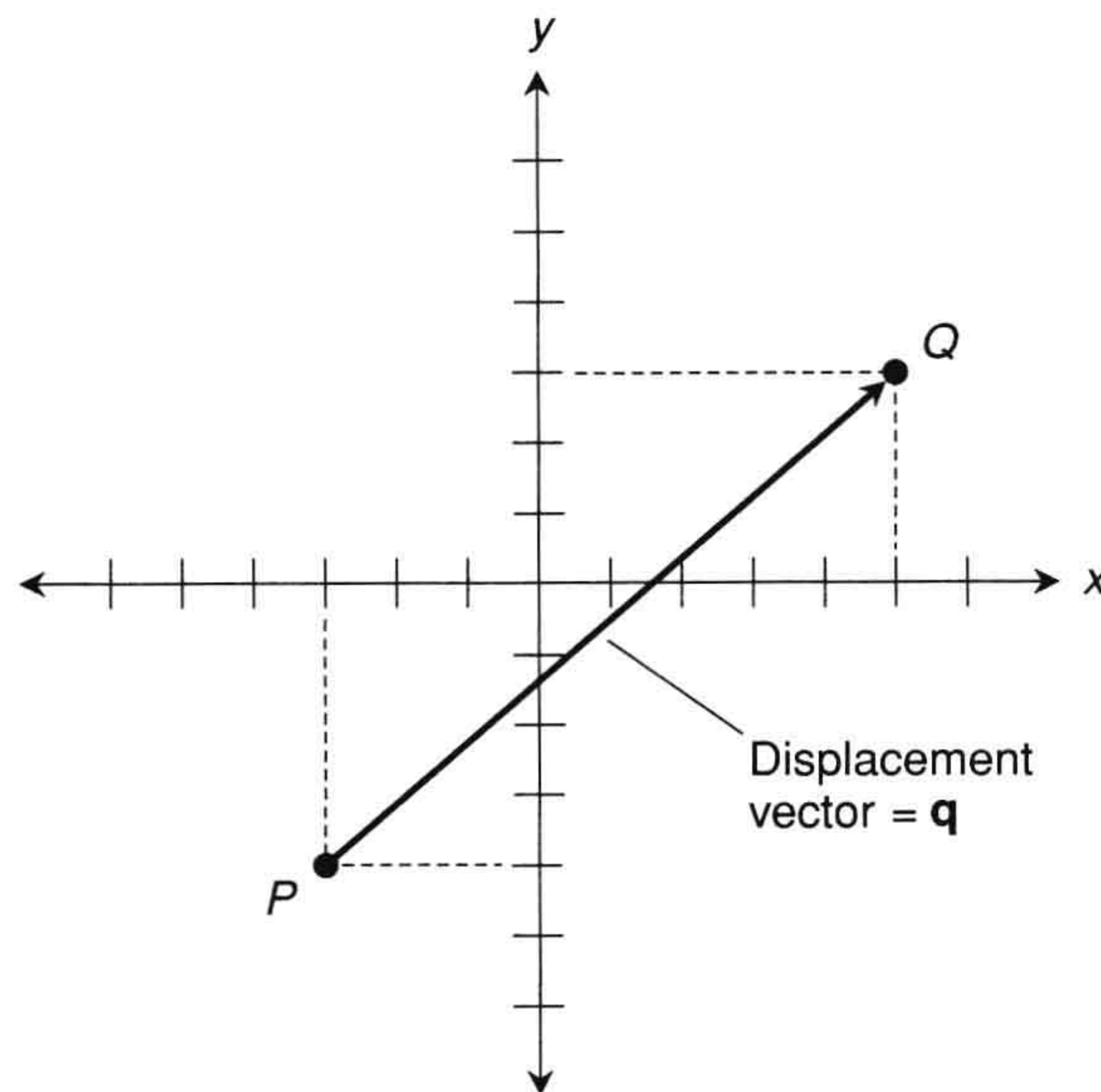
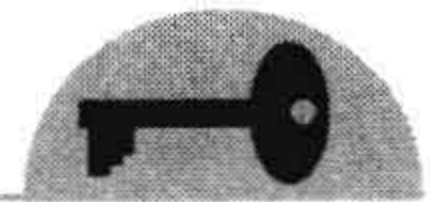
In linear motion, *displacement* is the difference in position or location between two points on a straight line. When displacement is defined from fixed some point  $P$  to another fixed point  $Q$ , it is a vector quantity because it has magnitude and direction. In this discussion, a general displacement vector is denoted by a lowercase boldface letter  $\mathbf{q}$ . Figure 1-1 is an example of a displacement vector that lies along a line  $PQ$  in *rectangular coordinates*.

The standard unit of linear displacement magnitude is the *meter*, symbolized by the lowercase letter  $m$ . Originally, the meter was designated as the distance between two scratches on a platinum bar on display in Paris, France, representing  $1/10,000,000$  ( $10^{-7}$ ) of the distance from the north geographic pole to the equator as measured along the meridian running through Paris. Nowadays, the meter can be defined as the distance a beam of light travels through a perfect vacuum in  $3.33564 \times 10^{-9}$  seconds.

## Velocity

*Velocity* consists of two independent components: magnitude (*speed*) and direction. Therefore, velocity is a vector quantity. The symbol for a general velocity vector





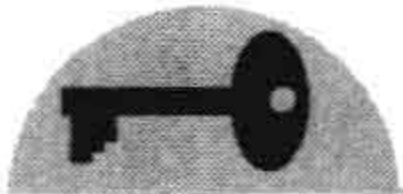
**Figure 1-1** A displacement vector in a two-dimensional Cartesian coordinate system.

is a lowercase bold letter  $\mathbf{v}$ . The common unit of velocity magnitude is the *meter per second* ( $\text{m/s}$  or  $\text{m} \cdot \text{s}^{-1}$ ). There is no formal absolute reference velocity because there is no absolute position or direction in the universe. However, we can consider the speed of light in a vacuum, in the absence of a gravitational field, to be a sort of “standard speed”:  $2.99792 \times 10^8 \text{ m/s}$ . As Albert Einstein first realized in the early 1900s, it always appears the same from any non-accelerating reference frame.

## LET IT BE SO!

You will often come across statements in mathematical texts, including this book, such as: “Let  $\mathbf{v}$  be a vector representing the velocity of an object  $S$ .” This language is customary. When you are told to *let* things be a certain way, you are being asked to *suppose* that they are that way. It is an invitation to let your imagination run wild! This sets the scene in your mind for hypotheses, logical arguments, or calculations to follow.





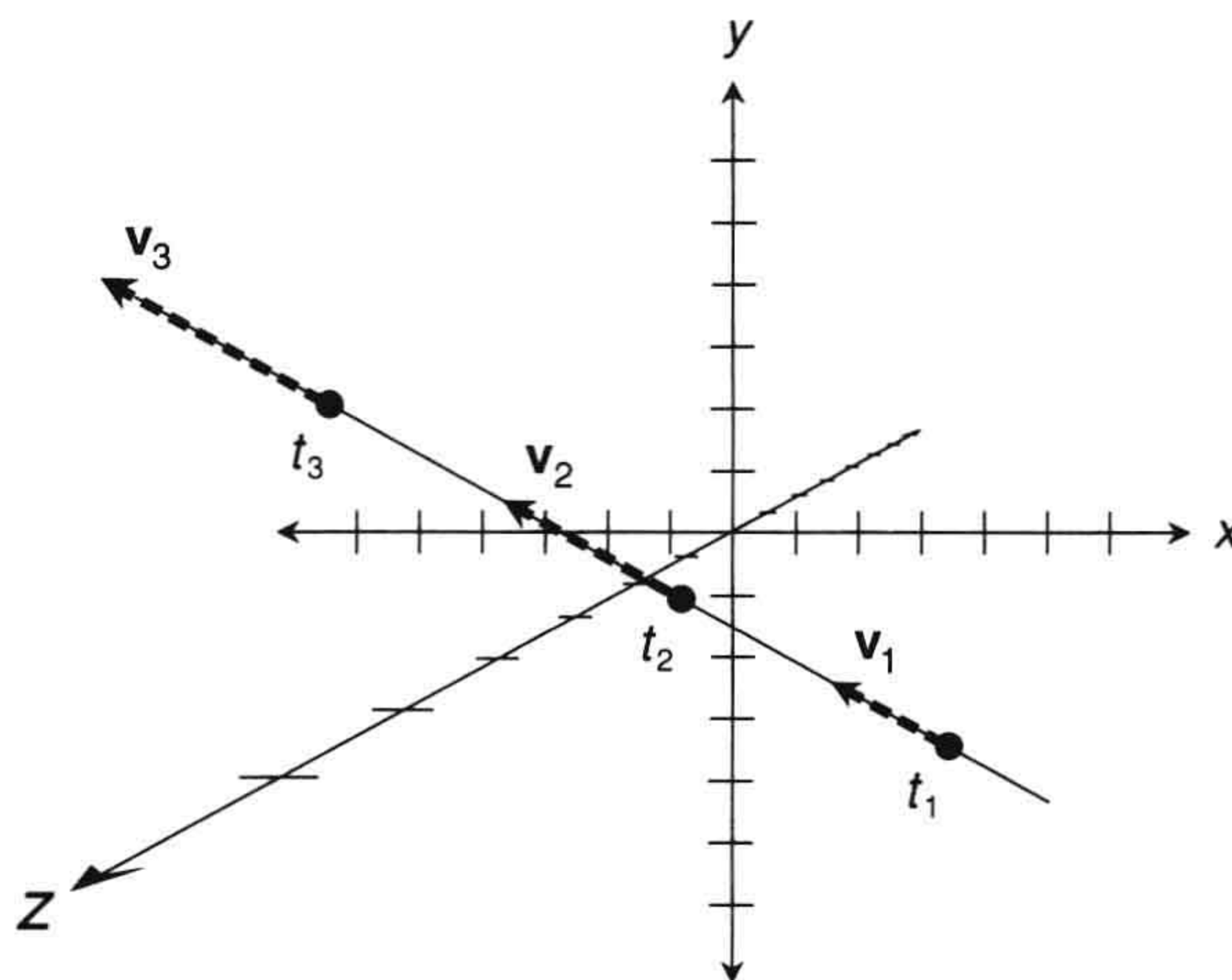
## EXPRESSIONS OF VELOCITY

Velocity can be considered as an *average* quantity over a certain period of time, or as an *instantaneous* quantity defined at a single point in time. Suppose you are driving along a straight road going due north at 25 m/s. Suddenly you see a bobcat. You hit the brakes to avoid hitting the cat, slow down to 10 m/s, watch the cat run away, and then speed up to 25 m/s again, all in a time span of one minute. Your average velocity over that minute might be 17 m/s due north. But your instantaneous velocity varies, and is 17 m/s due north at only two points in time (one as you slow down, the other as you speed back up).

Figure 1-2 shows three different velocity vectors  $\mathbf{v}_1$ ,  $\mathbf{v}_2$ , and  $\mathbf{v}_3$  in *rectangular three-space* for an object traveling along a straight line, speeding up as time goes by. The points  $t_1$ ,  $t_2$ , and  $t_3$  represent the instants in time at which the velocities of the object in question are  $\mathbf{v}_1$ ,  $\mathbf{v}_2$ , and  $\mathbf{v}_3$ , respectively. The magnitude of the velocity vector in each case is represented by the length of the dashed arrowed line.

## VELOCITY EQUATIONS

For constant velocity over a period of time, the following equations hold for time in seconds, displacement magnitude in meters, and velocity magnitude is in meters per second:



**Figure 1-2** Three velocity vectors (dashed arrowed lines) in a three-dimensional rectangular coordinate system for an object traveling in a straight line.