2. Motion in One Dimension

Strategy

Despite its importance, kinematics is often neglected in textbooks—probably because, once understood, the subtleties vanish and the subject appears trivial. However, many students fail to master the basic principles of kinematics. For example, few students understand the difference between position, distance traveled, and displacement even after completing an introductory course in physics. Another problem in teaching kinematics is that many students are unable to interpret even the simplest kinematic graphs. For those reasons, this chapter begins by analyzing a video sequence and from that analysis develops working definitions of position, displacement, average speed, and velocity and represents the motion graphically. Using the video sequence also reinforces the connection to the real world.

To better communicate the basic concepts, the chapter treats kinematics exclusively in one dimension, rather than immediately generalizing to two and three dimensions, and omits the customary historical narrative. Many students tend to have difficulties with mathematical operations with vectors. Building a strong foundation in vector operations with a single component enables students to more effectively treat vectors in all cases. The chapter is written so that a novice with no prior exposure to the ideas of motion can learn the material straight from the text. To keep more experienced students engaged, the text also contains many challenges and questions that will allow such students to deepen and broaden their knowledge.

This book is developed with the goal of minimizing the mathematics requirements early on so that students can get a better grasp of the physics without getting sidetracked by mathematics. (Even some Harvard students begin college with deficient math skills.) For that reason, the first nine chapters only deal with physics in one dimension. (Problems in more than one dimension are done simply by breaking them down into two or three problems in one dimension with some common constraints.) Once students have a solid grasp of physics in one dimension (horizontal, vertical, or along an incline), they can begin to explore two- and three-dimensional problems, including parabolic and rotational motion. This also gives students an opportunity to develop the required math skills in a concurrent mathematics course. Taking mathematics concurrent to physics, rather than as a prerequisite, can increase students' understanding of the mathematical concepts.

Overview

The presentation of kinematics begins by examining the motion recorded in a film clip. To analyze this motion, measurements of position and velocity are made directly from the sequence of video frames, and from these measurements, the ideas of coordinate system and time interval are developed. The measurements are then used to produce a position vs. time graph. Based on the graph, the chapter then discusses the process of representing a physical process by certain characteristics, thus simplifying the process so that it can be understood. The uncertainties in the measurement are used to introduce the concept of accuracy, and the measurements made on the film are calibrated to standard units of distance and time.

A choice of origin is required to define position, but a change in position (for example, a displacement) or the distance traveled over a certain period of motion can be defined without reference to a particular origin; likewise, a time interval does not depend on a specific "origin" of time, but a clock reading does. Velocity can be determined from the slope of an $x(t)$ curve or from the displacement during a certain time interval divided by that time interval. Finally, the Quantitative Tools section explores significant digits and the properties of scalars and vectors in more detail.

Distinctions between displacement and distance traveled, average and instantaneous quantities, and velocity and speed are clarified. In particular, the magnitude of the average velocity (displacement divided by time), which can be positive or negative, is shown not necessarily to be the same as the average speed (distance traveled divided by time), which is necessarily positive and is a scalar. Finally, the ideas of displacement as the area under a velocity vs. time curve and the instantaneous velocity as the derivative of the position with respect to time are introduced.

Topics That Are NOT Covered

The concept of acceleration is introduced in the next chapter (Chapter 3), although the qualitative part of this chapter is not restricted to constant-velocity motion.

Whereas the properties of vectors are carefully introduced, kinematics in two or more dimensions is introduced in Chapter 10, as is vector algebra in more than one dimension.

Terminology

Displacement is the change in position of an object undergoing motion.

Distance traveled is greater than displacement if the path taken by the object changes direction, such as if the motion in one dimension folds back on itself.

The $x(t)$ curve is used instead of another notation to emphasize that the curve drawn to represent motion in a position-versus-time graph can be fit with a mathematical function, $x(t)$. Similarly, for a velocity-versus-time graph, the $v(t)$ curve is used.

Notation and Visual Representations

Everything is in one dimension so that the appropriate treatment of vector or scalar properties of various kinematic quantities can be developed carefully, focusing on a single component. All vector operations involve treating the components of vectors appropriately. A vector is indicated by a letter with an arrow above it; the letter without the arrow denotes the (signed) magnitude of that vector; the magnitude of a vector is indicated by the letter between absolute value signs. The position vector in one dimension is represented as follows:

$$\vec{r} = x\hat{i}$$

The notation used in the text is presented in detail in sections 2.5 and 2.6 and is summarized in detail for the entire text in Appendix A. You should review it with students carefully because inconsistency in notation is very confusing to them.

Graphs of position and velocity vs. time are used extensively.

Cautionary Notes

Be careful to …

… be clear about the difference between distance traveled and displacement. This is a common difficulty for students.

… follow notation consistently and explain your use of it as you go. Students easily lose track of the difference between a vector, the signed magnitude of the vector, and the magnitude of the vector, and they may find it difficult to know which one is appropriate to use in a given context.

Common Student Difficulties and Concerns

- Understanding the difference between position, displacement, and distance traveled, particularly in trajectories that include round trips.
- Recognizing the difference between speed and velocity and between average and instantaneous velocity.
- Understanding the significance of the sign of an object’s velocity.
- Making, using, and interpreting graphs with time as the variable plotted on the *x* axis.
- Knowing how to construct velocity-versus-time graphs from position-versus-time graphs, and vice versa, and understanding the differences between different types of motion graphs.
- Interpreting changes in height and changes in slope (for example, is the object slowing down and which motion is slowest) and understanding the different meanings of the slope and height of the curve.
- Separating slope of a curve from path of motion.
- Interpreting the area under the curve.
- Matching narrative information with relevant features of a graph.
- Representing continuous motion by a continuous line.
- Representing a negative velocity on a velocity-versus-time graph.
- Connecting the motion of a real object to “model” motion (for example, motion of a point within a coordinate system), particularly when representing the motion of a complex object (for example, a person) that has parts that move relative to each other, it is easiest to represent the motion of a single point on the object.

Sample Recommendations from the *Practice* Text for Chapter 2

An example of the review questions that could be assigned to allow students to determine whether they are reading at the level of care required is suggested for each section below, with the difficulties addressed by the problem identified. The numbers in brackets correspond to the student difficulties that are directly related to the problem in the order they are listed. For instance, in Chapter 2, 12 student difficulties are mentioned, so the last in the list would be [12]. You might choose not to assign a question on each section for a day’s reading assignment, as two to four problems a day may be the best students can address sufficiently. Research has shown that as the assignment gets longer, many students do less on each question. You can choose a selection of problems that addresses a wider array of difficulties if you must limit the number of questions.

- Section 2.1: Review Question 1 [12]
- Section 2.2: Review Question 3 (adding question 4 is good if there is room in the assignment) [4,9,12]
- Section 2.3: Review Question 8 [1,4]
- Section 2.4: Review Question 9 [3,4,6,7]
- Section 2.5: Review Question 11 [this problem stresses good definitions more than it addresses other student difficulties]
- Section 2.6: Review Question 18 [1,3,4]
- Section 2.7: Review Question 23 [2,3,8]
- Section 2.8: Review Question 26 [8, possibly 11 according to how far the student takes the explanation]
- Section 2.9: Review Question 27 [2,3,4,5]

As the material is being covered, students should be encouraged to attempt a number of the "Developing a Feel" items and to work through the worked and guided problems with a pencil in hand, making sure they understand the approach. After a student has completed the reading and participated in the class activities associated with the material, you can assign a more challenging set of questions as homework. Alternatively, in a flipped classroom, these more difficult questions could be part of the work done in the classroom after content discussions were viewed and/or simple activities were done by students at home. For Chapter 2, an example set of problems that provides good coverage could be problems 18 [1,3,4,10], 59 [4,5,8], 66 [2], and context-rich problems 86 and 87 to allow students to use multiple ideas together. Context-rich problem 86 might be more accessible to students if it is assigned with the question "Can you make it?" Similarly, you could ask "Were the tortoise's workouts worth it?" for problem 87. The important thing in a context-rich problem is not to tell students specifically what to solve for, but it can be helpful, particularly with more novice learners, to give them a gentle nudge about in what general direction they should be heading.