preliminary edition

Tutorials *in* Introductory Physics

Lillian C. McDermott, Peter S. Shaffer
and the Physics Education Group

Department of Physics
University of Washington

Research · Curriculum · Instruction
Physics Education Group

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Preface

Tutorials in Introductory Physics is a set of instructional materials intended to supplement the lectures and textbook of a standard introductory physics course. The emphasis in the tutorials is not on solving the standard quantitative problems found in traditional textbooks, but on the development of important physical concepts and scientific reasoning skills.

There is increasing evidence that after instruction in a typical course, many students are unable to apply the physics formalism that they have studied to situations that they have not expressly memorized. In order for meaningful learning to occur, students need more assistance than they can obtain through listening to lectures, reading the textbook, and solving standard quantitative problems. It can be difficult for students who are studying physics for the first time to know what they do and do not understand and to learn to ask themselves the type of questions necessary to come to a functional understanding of the material. *Tutorials in Introductory Physics* provides a structure that promotes the active mental engagement of students in the process of learning physics. Questions in the tutorials guide students through the reasoning necessary to construct concepts and to apply them in real-world situations. The tutorials also provide practice in interpreting various representations (*e.g.,* formulas, graphs, diagrams, verbal descriptions) and in translating back and forth between them. For the most part, the tutorials are intended to be used after concepts have been introduced in the lectures and the laboratory, although most can serve to introduce the topic as well.

The tutorials comprise an integrated system of pretests, worksheets, and homework assignments. The tutorial sequence begins with a pretest. These are usually on material already presented in lecture but not yet covered in tutorial. The pretests help students identify what they do and not understand about the material and what they are expected to learn in the upcoming tutorial. They also inform the instructors about the level of student understanding. During a tutorial session, students work together on worksheets that provide the structure for these sessions. The worksheets consist of carefully sequenced tasks and questions. Students are expected to construct answers for themselves through discussions with their classmates and with tutorial instructors. The tutorial instructors do not lecture but ask questions designed to help students find their own answers. The tutorial homework reinforces and extends what is covered in the worksheets. For the tutorials to be most effective, it is important that course examinations include qualitative questions that emphasize the concepts and reasoning skills developed in the tutorials.

This preliminary edition of *Tutorials in Introductory Physics* contains a sufficient number of tutorials for a one-year course. Subsequent editions will include material on additional topics. The goal is to have enough tutorials to allow for two tutorial sessions each week.

The tutorials are designed for a small class setting that enables students to work together in groups of 3-4. However, in many cases, the materials can be adapted for use as interactive tutorial lectures. The tutorials are equally appropriate for calculus- and algebra-based courses.

Tutorials in Introductory Physics has been developed and tested at the University of Washington and pilot-tested at other colleges and universities.

Acknowledgments

Tutorials in Introductory Physics is the product of close collaboration by many members of the Physics Education Group at the University of Washington. Since 1991, when development of this curriculum began, significant contributions have been made by: Bradley Ambrose, Chris Border, Andrew Boudreaux, Patricia Chastain, Gregory Francis, Randal Harrington, Paula Heron, Stephen Kanim, Christian Kautz, Pamela Kraus, Michael Loverude, Graham Oberem, Luanna Gomez Ortiz, Tara O'Brien Pride, Christopher Richardson, Rachel Scherr, Mark Somers, Richard Steinberg, Stamatis Vokos, and Karen Wosilait, with special recognition for her work on the tutorials on waves and optics. The editorial assistance of Joan Valles in the preparation of this preliminary edition is deeply appreciated.

The collaboration of our colleagues in the Physics Department has been invaluable. Faculty who have been lecturers in the introductory calculus-based sequence, and graduate and undergraduate students who have served as tutorial instructors have made many useful comments. Among the students who have worked with us, Chris Becker and Scott Randol have been especially helpful.

Contributions have also been made by long-term visitors to our group. Since 1991, these have included: John Howell (Earlham College), Brian McInnes (University of Sydney), Daryl Pedigo (Austin Community College), E.F. (Joe) Redish (University of Maryland), Edwin Taylor (Boston University), and Walter Wales (University of Pennsylvania). Joe's enthusiasm for the project provided a major incentive for the publication of this Preliminary Edition. Physics instructors who have pilot-tested the tutorials and have provided valuable feedback include: Edward Adelson (The Ohio State University), John Christopher (University of Kentucky), James Freericks and Amy Liu (Georgetown University), Gregory Kilcup (The Ohio State University), Eunsook Kim (Seoul National University), Eric Mazur (Harvard University), James Poth (Miami University), E.F. Redish (University of Maryland), Jeff Saul (Prince George's Community College), and Beth Thacker (Grand Valley State University).

We thank our editor, Alison Reeves, for her encouragement and advice. We also gratefully acknowledge the support of the National Science Foundation, which has enabled the Physics Education Group to conduct the ongoing, comprehensive program of research, curriculum development, and instruction that has produced *Tutorials in Introductory Physics*. The tutorials have benefited from the past and concurrent development of *Physics by Inquiry* (©1996 John Wiley & Sons, Inc.), our other NSF-funded curriculum development project. *Tutorials in Introductory Physics* and *Physics by Inquiry* share a common research base and portions of each have been adapted for the other. We appreciate the cooperation of John Wiley & Sons, Inc. in facilitating this preliminary edition of *Tutorials in Introductory Physics*.

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VELOCITY

I. Motion with constant velocity

Each person in your group should obtain a ruler and at least one ticker tape segment from the staff. All the tape segments were generated using the same ticker timer. Do not write on or fold the tapes. If a ticker timer is available, examine it so that you are familiar with how it works.

A. Describe the motion represented by your segment of tape. Explain your reasoning.

B. Compare your tape with those of your partners.

How does the time taken to generate one of the short tape segments compare to the time taken to generate one of the long tape segments? Explain your answer.

Describe how you could use your answer above to arrange the tapes in order by speed.

C. Suppose the ticker timer that made the dots strikes the tape every $1/60^{th}$ of a second.

How far did the object that generated your tape segment move in: $1/60^{th}$ of a second? $2/60^{th}$ of a second? $3/60^{th}$ of a second? Explain your answer.

Predict how far the object would move in: 1 second, $1/120^{th}$ of a second. Explain the assumption(s) you used to make your predictions.

D. In your own words, describe the procedure you would use to calculate the speed of an object.

Determine the speed of the object that generated each of your tapes. Record your answers below.

Give an interpretation of the speed of the object, *i.e.,* explain the meaning of the number you just calculated. Do not use the word "speed" in your answer. (*Hint:* Which of the distances that you calculated in part C is numerically equal to the speed?)

Write the speed of the object that generated each tape on a small piece of paper and attach the paper to the tape. Express your answer in terms of centimeters and seconds.

E. A motion that generates a sequence of evenly-spaced dots on a ticker tape is called motion with *constant velocity*. Explain the assumption about the motion that is being made when this phrase is applied.

Discuss with your partners whether the object that generated your tape was moving with constant velocity.

F. A model train moving with constant velocity travels 60 cm for every 1.5 s that elapses. Answer the questions below and discuss your reasoning with your partners.

1. Is there a name that is commonly given to the quantity represented by the number 40? (40 = 60/1.5) If so, what is the name?

   To denote the quantity completely, what additional information must be given besides the number 40?

   How would you *interpret* the number 40 in this instance? (*Note:* A name is *not* an interpretation. Your response should be in terms of centimeters and seconds.)

   Use your interpretation (not algebra) to find the distance the train moves in 2.5 s.

2. Is there a name that is commonly given to the quantity represented by the number 0.025? (0.025 = 1.5/60) If so, what is the name?

   How would you *interpret* the number 0.025?

   Use your interpretation (not algebra) to find the time it takes the train to move 90 cm.

II. Motion with varying speed

A. In the space below, sketch a possible ticker tape resulting from motion with varying speed and write a description of the motion.

How can you tell from your diagram that the motion has varying speed?

B. Together with your classmates, take your ticker tapes and arrange yourselves in a line, ranked according to the speed of the tapes. Discuss the following questions as a class.

Compare your segment of ticker tape to neighboring tape segments. What do you observe?

Compare the smallest and largest speeds. What do you observe?

C. Based on your observations of your tape and the tapes of other members of your class, answer the following questions.

Is each small tape segment a part of a motion with constant or varying speed?

Did your examination of a single, small tape segment reveal whether the motion that generated the entire tape had constant or varying speed?

D. Review your earlier interpretation of the speed for your small tape segment. (See section I.) Is that interpretation valid for the motion that generated the entire tape?

Based on the speed for your piece of tape, could you successfully predict how far the object would move in: $1/60^{th}$ s? $2/60^{th}$ s? 1 s?

How can you modify the interpretation of the speed so that it applies even to motion with varying speed?

What name is given to a speed that is interpreted in this way?

E. Suppose you selected two widely separated dots on the assembled ticker tape. What would you call the number you would obtain if you divided the distance between the dots by the time it took the object to move between the dots?

How would you interpret this number?

REPRESENTATIONS OF MOTION

In this tutorial, you will use a motion detector to graph your motion and to investigate how motion can be described in terms of position, velocity, and acceleration. See your instructor for instructions on using the equipment.

General tips

When using a motion detector:

- Stay in line with the detector and do not swing your arms. For best results, take off bulky sweaters or other loose-fitting clothing. You may find it helpful to hold a large board in front of you in order to present a larger target for the detector.
- Do not stand closer than 0.5 meter or farther than 4 meters from the detector.
- It is difficult to obtain good *a* versus *t* graphs with the motion detector. Discuss any questions about your *a* versus *t* graphs with an instructor.

Instructions

In each of the following problems, you will be given one of the following descriptions of a motion:

- a written description, or
- an *x* versus *t*, *v* versus *t*, or *a* versus *t* graph.

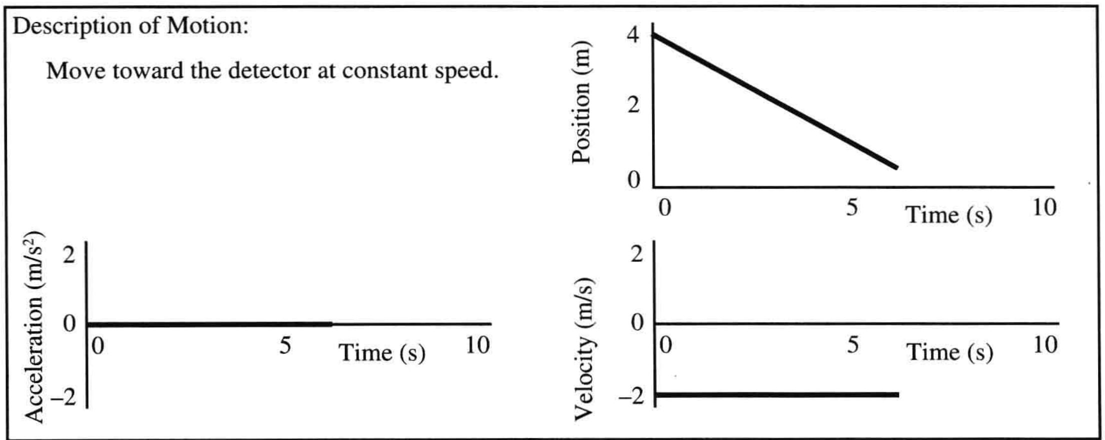
Predict the other three descriptions of the motion, then use the motion detector to check your answers. Check your predictions one-by-one, instead of checking a whole page at once. In addition, answer the questions posed at the bottom of each page.

Note: So that your graphs emphasize important features, draw them in an idealized form rather than showing many small wiggles.

Example: The problem below has been worked as an example. Use the motion detector to verify the answers.

Description of Motion:

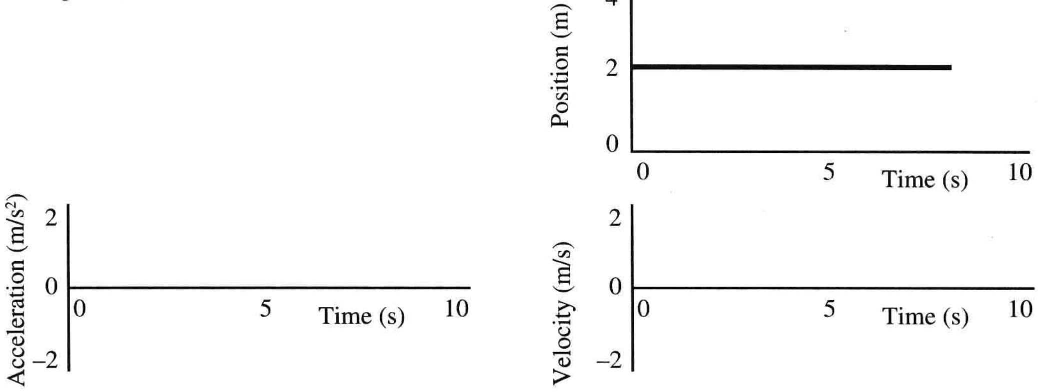
Move toward the detector at constant speed.



The computer program assumes a particular coordinate system. Describe this coordinate system.

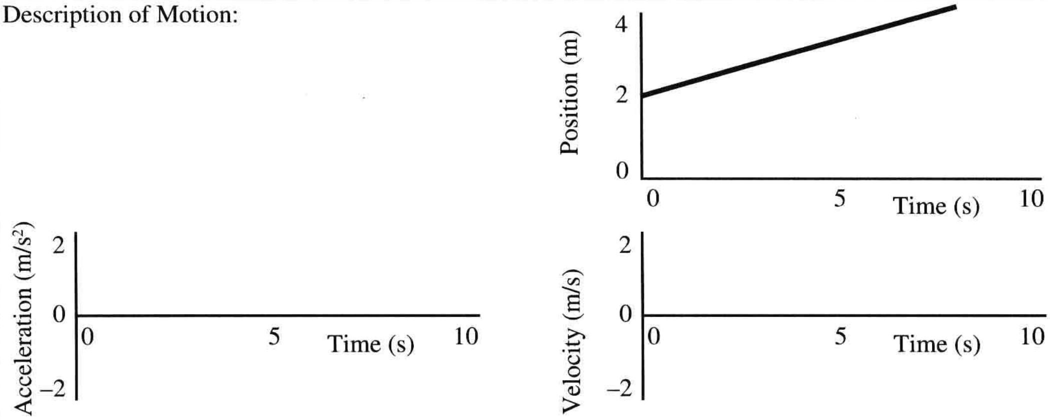
A.

Description of Motion:



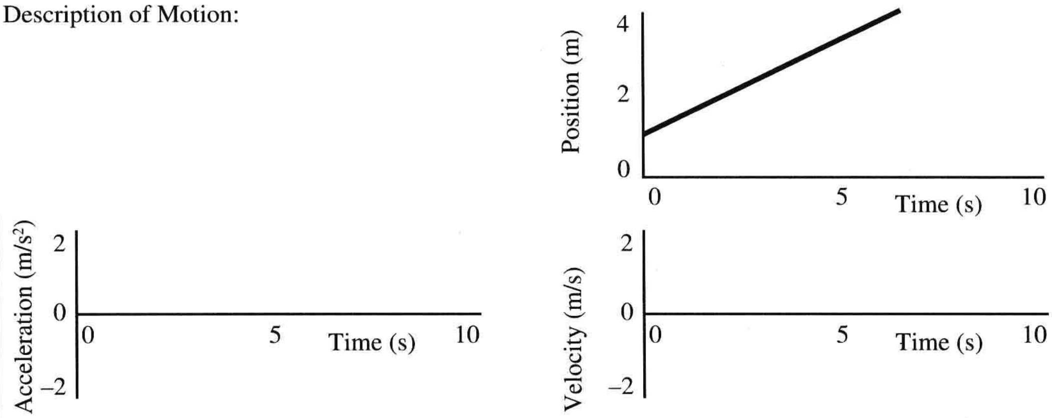
B.

Description of Motion:



C.

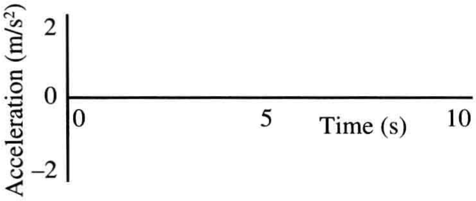
Description of Motion:

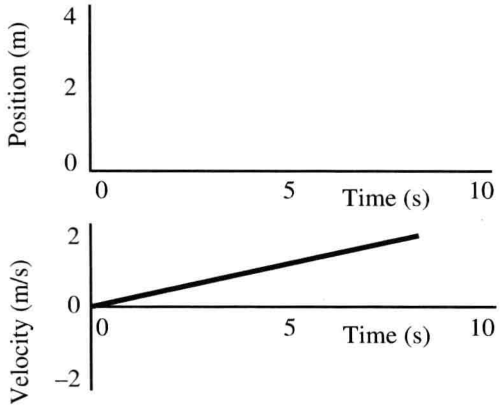


How are the motions of B and C similar? How do they differ? How are the graphs similar? How do they differ?

D.

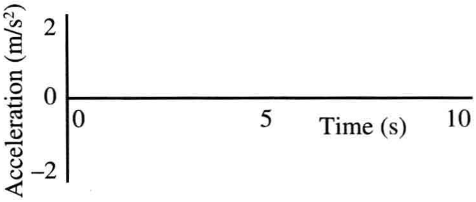
Description of Motion:

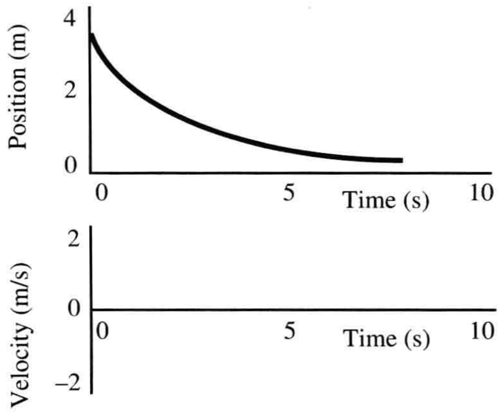




E.

Description of Motion:

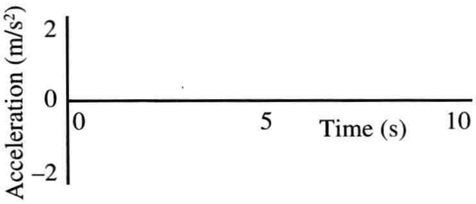


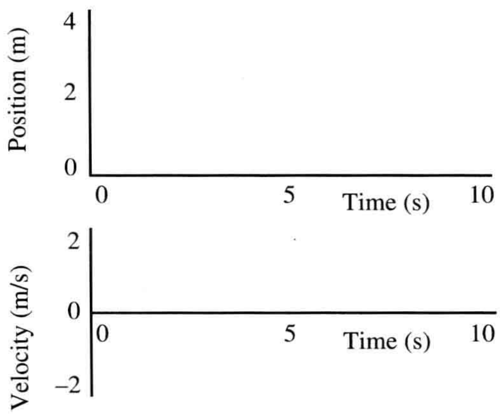


F.

Description of Motion:

Move toward the detector with decreasing speed, then just as you have come to rest, move away from the detector with increasing speed.





How do the acceleration graphs for D, E, and F compare? Is it possible to: have a positive acceleration and slow down? have a negative acceleration and speed up?