

RealTime Physics

Active Learning Laboratories

MODULE 1 MECHANICS

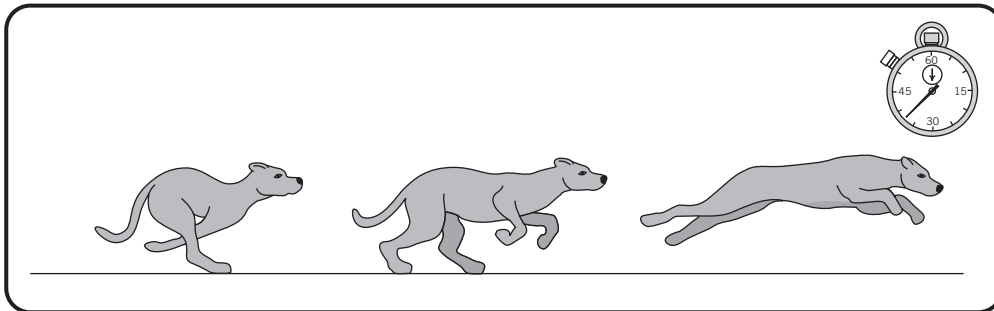
**DAVID R. SOKOLOFF
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RealTime Physics

Active Learning Laboratories

Module 1

Mechanics



A cheetah can accelerate from 0 to 50 miles per hour in 6.4 seconds.

—Encyclopedia of the Animal World

A Jaguar can accelerate from 0 to 50 miles per hour in 6.1 seconds.

—World Cars

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Preface

Development of the series of *RealTime Physics (RTP)* laboratory guides began in 1992 as part of an ongoing effort to create high-quality curricular materials, computer tools, and apparatus for introductory physics teaching.¹ The *RTP* series is part of a suite of *Activity-Based Physics* curricular materials that include the *Tools for Scientific Thinking* laboratory modules,² the *Workshop Physics* Activity Guide,^{3,4} and the *Interactive Lecture Demonstration* series.^{5,6} The development of all of these curricular materials has been guided by the outcomes of physics education research. This research has led us to believe that students can learn vital physics concepts and investigative skills more effectively through guided activities that are enhanced by the use of powerful microcomputer-based laboratory (MBL) tools.

MBL tools—originally developed at Technical Education Research Centers (TERC) and at the Center for Science and Mathematics Teaching, Tufts University—have become increasingly popular for the real-time collection, display, and analysis of data in the introductory laboratory. MBL tools consist of electronic sensors, a microcomputer interface, and software for data collection and analysis. Sensors are available for many quantities including motion, force, sound, magnetic field, current, voltage, temperature, pressure, rotary motion, acceleration, humidity, light intensity, pH, and dissolved oxygen.

MBL tools provide a powerful way for students to learn physics concepts. For example, students who walk in front of an ultrasonic motion sensor while the software displays position, velocity, or acceleration in real time more easily discover and understand motion concepts. They can see a cooling curve displayed instantly when a temperature sensor is plunged into ice water, or they can sing into a microphone and see a pressure vs. time plot of sound intensity.

MBL data can also be analyzed quantitatively. Students can obtain basic statistics for all or a selected subset of the collected data and then either fit or model the data with an analytic function. They can also integrate, differentiate, or display a fast Fourier transform of data. Software features enable students to generate and display *calculated quantities* from collected data in real time. For example, since mechanical energy depends on mass, position, and velocity, the time variation of potential and kinetic energy of an object can be displayed graphically in real time. The user just needs to enter the mass of the object and the appropriate energy equations ahead of time.

The use of MBL tools for both conceptual and quantitative activities, when coupled with developments in physics education research, has led us to expand our view of how the introductory physics laboratory can be redesigned to help students learn physics more effectively.

COMMON ELEMENTS IN THE *REALTIME PHYSICS* SERIES

Each laboratory guide includes activities for use in a series of related laboratory sessions that span an entire quarter or semester. Lab activities and homework assignments are integrated so that they depend on learning that has occurred during the previous lab session and also prepare students for activities in the next session. The major goals of *RealTime Physics* are: (1) to help students acquire an understanding of a set of related physics concepts; (2) to provide students with direct experience of the physical world by using MBL tools for real-time data collection, display and analysis; (3) to enhance traditional laboratory skills; and

(4) to reinforce topics covered in lectures and readings using a combination of conceptual activities and quantitative experiments.

To achieve these goals we have used the following design principles for each module based on educational research.

- The materials for the weekly laboratory sessions are sequenced to provide students with a coherent observational basis for understanding a single topic area in one semester or quarter of laboratory sessions;
- The laboratory activities invite students to construct their own models of physical phenomena based on observations and experiments;
- The activities are designed to help students modify common preconceptions about physical phenomena that make it difficult for them to understand essential physics principles;
- The activities are designed to work best when performed in collaborative groups of 2 to 4 students;
- MBL tools are used by students to collect and graph data in real time so they can test their predictions immediately;
- A learning cycle is incorporated into each set of related activities that consists of prediction, observation, comparison, analysis, and quantitative experimentation;
- Opportunities are provided for class discussion of student ideas and findings;
- Each laboratory includes a pre-lab warm-up assignment, and a post-lab homework assignment that reinforces critical physics concepts and investigative skills.

The core activities for each laboratory session are designed to be completed in two hours. Extensions have been developed to provide more in-depth coverage when longer lab periods are available. The materials in each laboratory guide are comprehensive enough that students can use them effectively even in settings where instructors and teaching assistants have minimal experience with the curricular materials.

The curriculum has been designed for distribution in electronic format. This allows instructors to make local modifications and reprint those portions of the materials that are suitable for their programs. The *Activity-Based Physics* curricular materials can be combined in various ways to meet the needs of students and instructors in different learning environments. The *RealTime Physics* laboratory guides are designed as the basis for a complete introductory physics laboratory program at colleges and universities. But they can also be used as the central component of a high school physics course. In a setting where formal lectures are given, we recommend that the *RTP* laboratories be used in conjunction with *Interactive Lecture Demonstrations*.⁶

THE MECHANICS LABORATORY GUIDE

The primary goal of this *RealTime Physics Mechanics* guide is to help students achieve a solid understanding of classical mechanics including Newton's three laws of motion. A number of physics education researchers have documented that most students begin their study of mechanics with conceptions about the nature of motion that can inhibit their learning of Newton's Laws.⁷

Newtonian dynamics is basically a study of the relationship between force and motion. The simultaneous use of an MBL force probe and motion sensor is powerful because students can display force-time graphs in real time along with any combination of graphs of position, velocity and/or acceleration versus time. The availability of a low-friction dynamics cart and track system makes possible observations of forces and the resulting motions initially in the simplest possible cases.

A critical aspect of *RealTime Physics Mechanics* is the use of a different order of presentation of topics than that used in popular textbooks. This order of topics, which we have dubbed the *New Mechanics* sequence, is based on our own experience with class testing and evaluation of the *Tools for Scientific Thinking* and *Workshop Physics* curricula. Based on earlier suggestions by Rothman⁸ and Arons,⁹ we have re-sequenced activities in both *RealTime Physics* and *Workshop Physics* to treat one-dimensional kinematics and dynamics before any two-dimensional motions are considered, and to introduce linear momentum before energy. The *New Mechanics Sequence* is described in more detail elsewhere.¹⁰ The key elements are:

- One-dimensional kinematics and dynamics are treated before two-dimensional situations.
- Newton's Second Law is developed before Newton's First Law.
- The relationship between visible applied forces and motions in situations where friction is negligible is treated before the consideration of other types of forces.
- The "invention" of invisible forces such as sliding friction and gravity is encouraged as a way to preserve the viability of the Newtonian Schema for predicting motions.
- Newton's Third Law is developed through direct observations of the interaction forces between objects both during short-duration collisions and when objects are in contact for longer times.
- Momentum concepts are treated before the introduction of mechanical energy concepts.

RealTime Physics Mechanics includes 12 labs covering kinematics, dynamics, gravitational forces, passive forces, projectile motion, impulse and momentum, and work and energy.

Labs 1 and 2 (Introduction to Motion and Changing Motion): These labs involve the study of one-dimensional kinematics using an MBL system with a motion sensor. After recording their own body motions, students use a battery-operated fan unit mounted on a low-friction dynamics cart to produce constant accelerations.

Labs 3 through 7 (Force and Motion, Combining Forces, Force, Mass and Acceleration, Gravitational Forces, and Passive Forces and Newton's Laws): These labs require students to develop observational evidence for Newton's First and Second Laws. A force probe and motion sensor are used so that students can measure the position, velocity, and acceleration of a dynamics cart and other objects while simultaneously recording the applied forces.

Labs 8 and 9 (One-dimensional Collisions and Newton's Third Law and Conservation of Momentum): In these labs students use the same apparatus to observe momentum changes and impulses during one-dimensional collisions.

Students also observe collision forces on a moment-by-moment basis, using force probes mounted on interacting carts, to explore the meaning and validity of Newton's Third Law.

Lab 10 (Two-dimensional Motion—Projectile Motion): This lab allows students to explore the kinematics and dynamics of two-dimensional motions of objects moving under the influence of the invisible gravitational force using analysis of a video of projectile motion.

Labs 11 and 12 (Work and Energy and Conservations of Energy): These labs involve the exploration of work and energy, using an MBL motion sensor to display the kinetic energy of a moving cart in real time. The conservation of mechanical energy is explored in two systems: a low-friction cart on an inclined ramp and a mass oscillating at the end of a spring.

ON-LINE TEACHERS' GUIDE

The *Teachers' Guide for RealTime Physics Mechanics* is available on-line at <http://www.wiley.com/college/sokoloff>. This *Guide* focuses on pedagogical (teaching and learning) aspects of using the curriculum, as well as computer-based and other equipment. The *Guide* is offered as an aid to busy physics educators and does not pretend to delineate the "right" way to use the *RealTime Physics Mechanics* curriculum and certainly not the MBL tools. There are many right ways. The *Guide* does, however, explain the educational philosophy that influenced the design of the curriculum and tools and suggests effective teaching methods. Most of the suggestions have come from the college, university, and high school teachers who have participated in field testing of the curriculum.

The *On-line Teachers' Guide* has thirteen sections. Section I presents suggestions regarding computer hardware and software to aid in the implementation of this activity-based MBL curriculum. Sections II through XIII present information about the twelve different labs. Included in each of these is information about the specific equipment and materials needed, tips on how to optimize student learning, answers to questions in the labs, and complete answers to the homework.

EXPERIMENT CONFIGURATION FILES

Experiment configuration files are used to set up the appropriate software features to go with the activities in these labs. You will either need the set of files which is designed for the software package you are using, or you will need to set up the files yourself. At this writing, experiment configuration files for *RealTime Physics Mechanics* are available with Vernier Software and Technology, *Logger Pro* (for Windows and Macintosh), and with PASCO *Data Studio* (for Macintosh and Windows). Appendix A of this module outlines the features of the experiment configuration files for *RealTime Physics Mechanics*. For more information, consult the *On-line Teachers' Guide*.

CONCLUSIONS

RealTime Physics Mechanics has been used in a variety of different educational settings. Many university, college, and high school faculty who have used this curriculum have reported improvements in student understanding of Newton's Laws. Their comments are supported by our careful analysis of pre- and post-test

data using the *Force and Motion Conceptual Evaluation* reported in the literature.^{11,12,13} Similar research on the effectiveness of *RealTime Physics Electricity and Magnetism*,¹⁴ *Heat and Thermodynamics* and *Light and Optics* also show dramatic conceptual learning gains in these topic areas. We feel that by combining the outcomes of physics educational research with microcomputer-based tools, the laboratory can be a place where students acquire both a mastery of difficult physics concepts and vital laboratory skills.

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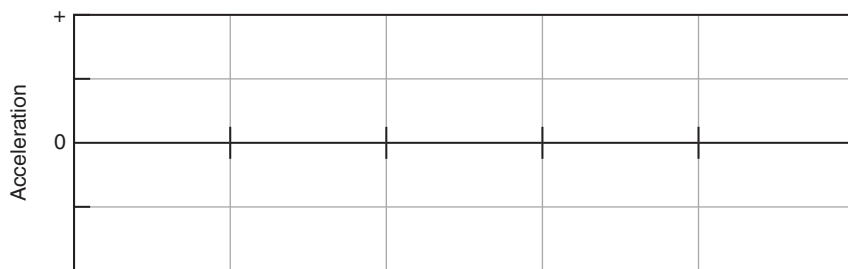
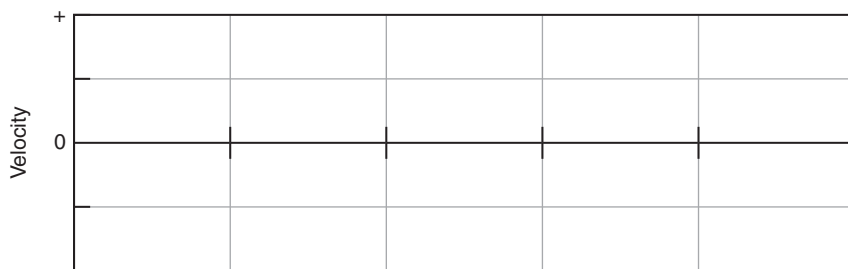
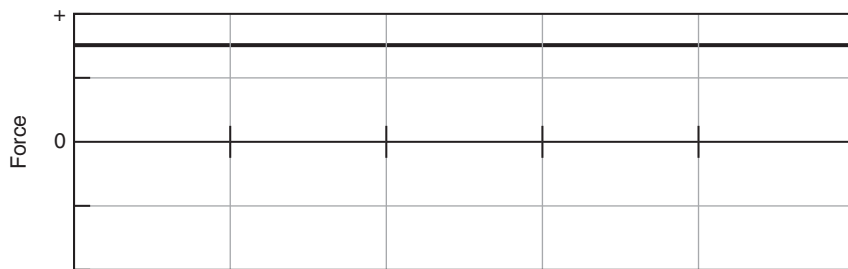
PRE-LAB PREPARATION SHEET FOR LAB 3: FORCE AND MOTION

(Due at the beginning of Lab 3)

Directions:

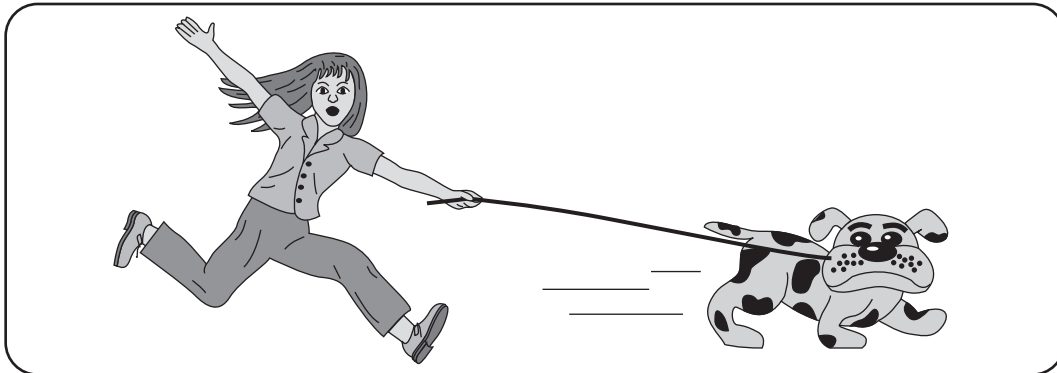
Read over Lab 3 and then answer the following questions about the procedures.

1. What is the purpose of the rubber bands in Activity 1-1?
2. What is the difference between a *linear* and a *proportional* relationship?
3. Why is it necessary that a force probe be calibrated?
4. Sketch your Prediction 2-2 below.



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LAB 3: FORCE AND MOTION



A vulgar Mechanik can practice what he has been taught or seen done, but if he is in an error he knows not how to find it out and correct it, and if you put him out of his road, he is at a stand; whereas he that is able to reason nimbly and judiciously about figure, force and motion, is never at rest til he gets over every rub.

—Isaac Newton

OBJECTIVES

- To develop a method for measuring forces reliably.
- To learn how to use a force probe to measure force.
- To explore how the motion of an object is related to the forces applied to it.
- To find a mathematical relationship between the force applied to an object and its acceleration.

OVERVIEW

In the previous labs, you have used a motion detector to display position–time, velocity–time, and acceleration–time graphs of different motions of various objects. You were not concerned about how you got the objects to move, i.e., what forces (pushes or pulls) acted on the objects. From your own experiences, you know that force and motion are related in some way. To start your bicycle moving, you must apply a force to the pedal. To start up your car, you must step on the accelerator to get the engine to apply a force to the road through the tires.

But exactly how is force related to the quantities you used in the previous lab to describe motion—position, velocity, and acceleration? In this lab you will pay attention to forces and how they affect motion. You will first develop an idea of a force as a push or a pull. You will learn how to measure forces. By applying forces to a cart and observing the nature of its resulting motion graphically with a motion detector, you will come to understand the effects of forces on motion.

INVESTIGATION 1: MEASURING FORCES

In this investigation you will explore the concept of a constant force and the combination of forces in one dimension. You can use these concepts to learn how to measure forces with a force probe. You will need the following materials:

- computer-based laboratory system
- *RealTime Physics Mechanics* experiment configuration files
- force probe
- five identical rubber bands
- meter stick
- spring scale with a maximum reading of 5 N

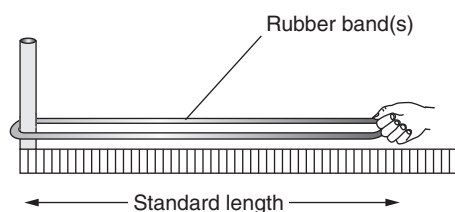
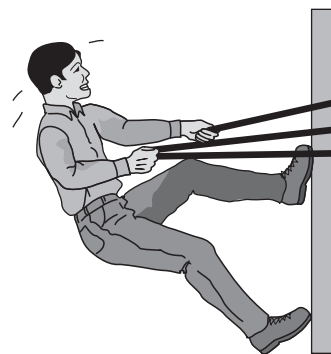
Activity 1-1: How Large Is a Pull?

If you pull on a rubber band attached at one end, you know it will stretch. The more you pull, the more it stretches. Try it.

1. Attach one end of the rubber band to something on the table that can't move. Also attach the meter stick to the table. Now stretch the rubber band so it is several centimeters longer than its relaxed length. Does it always seem to exert the *same* pull on you each time it is stretched to the *same* length? (Most people agree that this is obvious.)
2. Write down the length you have chosen in the space below. This will be your *standard length* for future measurements.

Standard length of rubber band = _____ cm

3. Attach one end of each of two identical rubber bands to something that can't move and stretch them together side-by-side to the standard length.



Question 1-1: How does the combined force of two rubber bands compare to what you felt when only one rubber band was used?

4. Repeat this comparison of how strong the forces feel with three, four, and five rubber bands stretched together to the same standard length.

Question 1-2: Suppose you stretched a rubber band to your standard length by pulling on it. Now you want to create a force six times as large. How could you create such a force?

Question 1-3: Suppose you applied a force with a stretched rubber band one day, and several days later you wanted to feel the same force or apply it to something. How could you assure that the forces were the same? Explain.

Question 1-4: Do side-by-side rubber bands provide a convenient way of accurately reproducing forces of many different sizes? Explain.

You have seen that pulling more rubber bands to the same length requires a larger pull. To be more precise about the pulls and pushes you are applying, you need a device to measure forces accurately. The electronic force probe is designed to do this.

Activity 1-2: Measuring Forces with a Force Probe

In this activity you will explore the capability of an electronic force probe as a force measuring device.

1. Plug the force probe into the computer interface. Display force vs. time axes by opening the experiment file called **Measuring Force (L03A1-2a)**.

If the sensitivity of your force probe can be adjusted, choose the setting appropriate to the measurements in this activity (about 0 to 10 N or more).

Comment: Since forces are detected by the computer system as *changes* in an electronic signal, it is important to have the computer “read” the signal when the force probe has no force pushing or pulling on it. This process is called “zeroing.” Also, the electronic signal from the force probe can change slightly from time to time as the temperature changes. Therefore, if it is possible to **zero** your force probe, it is a good idea to do so with nothing attached to the probe before making each measurement.

2. If possible, **zero** the force probe with nothing pulling on it.
3. Attach one end of a rubber band to something that can't move, as before, and the other end to the force probe hook. Pull horizontally on the rubber band with the force probe until the band is stretched to the same *standard length* used in Activity 1-1, and **begin graphing** while holding the rubber band steady for the whole graph.

Record a typical force probe reading: _____

(Use the **analysis feature** of the software to get an accurate reading of the force.)

- Although you could continue to take data with multiple rubber bands in the same way you did with just one, the easiest way to take these data is to open the experiment file called **Rubber Bands (L03A1-2b)**. This experiment sets the software in **event mode** and allows you to plot the measured force against the number of rubber bands by manually entering the number when prompted.

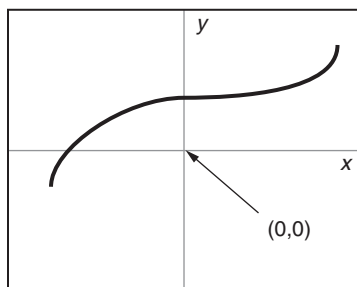
After loading, **zero** the force probe and then **begin graphing**. The force probe reading will be displayed on the graph continuously until you decide to **keep** the value.

Keep the force values with 0, 1, 2, 3, 4, and 5 rubber bands pulled by the force probe to your standard length. **Stop** graphing when you are done.

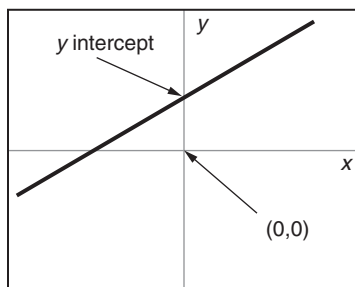
- Record the force probe reading for each number of rubber bands in the table below. (You may use the **analysis feature** of the software to get accurate force readings.)

Number of rubber bands	0	1	2	3	4	5
Force probe reading (arbitrary units)						

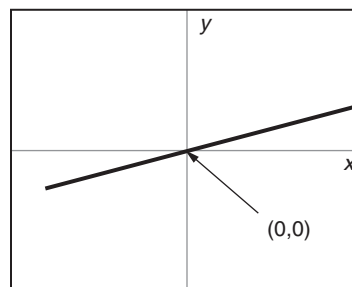
Comment: We are interested in the nature of the mathematical relationship between the reading of the force probe and force (in rubber band units). This can be determined from the graph by drawing a smooth curve that fits the plotted data points. Some definitions of possible mathematical relationships are shown below. In these examples, y might be the force probe reading and x the number of rubber bands.



y is a function of x , which increases as x increases.



y is a *linear* function of x , which increases as x increases according to the mathematical relationship $y = mx + b$, where b is a constant called the *y intercept*.



y is *proportional* to x . This is a special case of a linear relationship where $y = mx$, and b , the *y intercept*, is zero.

These graphs show the differences between these three types of mathematical relationship. y can increase as x increases, and the relationship doesn't have to be *linear* or *proportional*. *Proportionality* refers only to the special linear relationship where the *y intercept* is zero, as shown in the example graph on the right.

- The **fit routine** of your software allows you to determine the relationship by trying various curves to see which best fits the plotted data. Try a linear fit: $F = c + bx$ and any other that you think is appropriate.

When you have found a good fit, where the curve goes through or close to all of the data points, **print** the graph along with the fit equation, and affix it in the space below.

Question 1-5: How are force probe readings related to the size of the pull exerted by the force probe hook on the rubber bands? Describe the mathematical relationship in words.

Question 1-6: Based on your graph, what force probe reading corresponds to the pull of one rubber band when stretched to your standard length? How did you determine this?

Comment: You can use your measurements to define a quantitative force scale. You might call it the “rubber band scale,” or give it yours or your partner’s name. Whenever the force probe has the reading corresponding to the pull of one rubber band stretched the standard length, the force is equivalent to one “rubber band,” or one “Mary” or one “Sam.” Any larger force can be measured as some number of these units.

Your graph relates two different ways of measuring force, one with standard stretches of different numbers of rubber bands (rubber band units) and the other with a force probe. Such a graph is called a *calibration curve* and is used to compare measurements of quantities made with two different measuring instruments. You could use it to convert forces measured in force probe units to rubber band units, and vice versa.

Physicists have defined a standard unit of force called the *newton*, abbreviated N. For the rest of your work on forces and the motions they cause, it will be more convenient to have the force probe read directly in newtons. Then the forces you measure can be compared to forces anyone else measures. Most spring scales have already been calibrated in newtons. All you need to do is to calibrate the force probe to read forces in newtons by using the spring scale to input standard force measurements.

If you have extra time, do the following Extension to examine the importance of a linear force scale like that of the spring scale.

Extension 1-3: Importance of Linear Force Scales

You have probably observed in Activity 1-2 that a force scale based on the force probe is approximately a proportional one. That is, if you apply twice as large a force (e.g., by pulling two side-by-side rubber bands rather than one to the standard length) the force probe gives just about twice the reading. Not all devices give a proportional force scale.

Use the force probe to examine the force scales produced by (1) a single rubber band and (2) a spring, each stretched to various lengths. That is, set up experiments to graph the force applied as a function of length for each of these.

Question E1-7: Based on your graphs, is either of these force scales proportional? What are the advantages of using a proportional force scale?

Activity 1-4: Calibrating the Force Probe

Comment: Most strain gauge type force probes come with a good calibration. In this activity you can check the calibration of your probe. However, in the activities that follow, you can depend on the calibration that came with your probe.

1. Open the experiment file called **Calibrating Force (L03A1-4)**.
2. Check the calibration. First **zero** the force probe. Then **begin graphing**, and pull on the force probe with the spring scale with several different forces, each 2.0 N or smaller. Record the spring scale readings in the table below, and then use the **analysis feature** of the software and record the corresponding force probe readings.

Spring scale reading (N)			
Force probe reading (N)			

Question 1-8: Do your force probe readings correspond to your spring scale readings? Can you use the force probe to make reasonably accurate force measurements?

INVESTIGATION 2: MOTION AND FORCE

Now you can use the force probe to apply known forces to an object. You can also use the motion detector, as in the previous two labs, to examine the motion of the object. In this way you will be able to explore the relationship between motion and force.

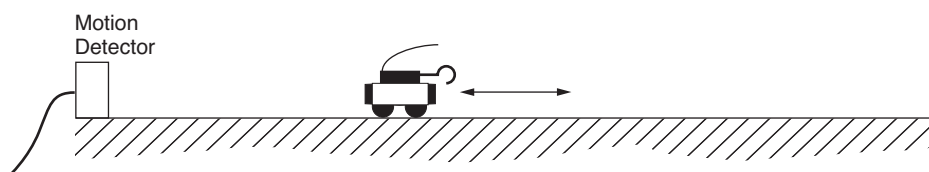
You will need the following materials:

- computer-based laboratory system
- *RealTime Physics Mechanics* experiment configuration files
- force probe
- motion detector
- cart with very little friction
- masses to increase cart's mass to about 1 kg
- smooth ramp or other level surface 1.2–2.5 m long
- low-friction pulley, lightweight string, table clamp, variety of hanging masses

Activity 2-1: Pushing and Pulling a Cart

In this activity you will move a low friction cart by pushing and pulling it with your hand. You will measure the force, velocity, and acceleration. Then you will be able to look for mathematical relationships between the applied force and the velocity and acceleration, to see whether either is (are) related to the force.

1. Set up the cart, force probe, and motion detector on a smooth level surface as shown below. The cart should have a mass of about 1 kg with force probe included. Fasten additional mass to the top if necessary.

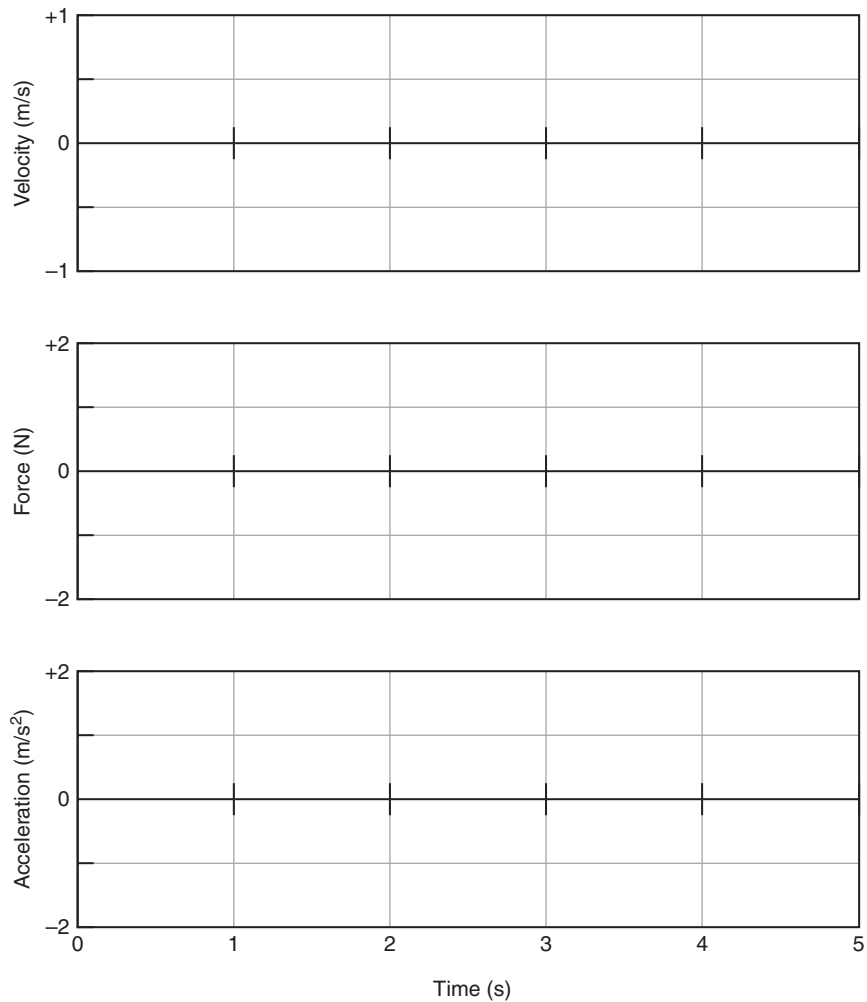


The force probe should be fastened *securely* to the cart so that its body and cable do not extend beyond the end of the cart facing the motion detector. (Tape the force probe cable back along the body to assure that it will not be seen by the motion detector.)

Prediction 2-1: Suppose you grasp the force probe hook and move the cart forward and backward in front of the motion detector. Do you think that either the velocity or the acceleration graph will look like the force graph? Is either of these motion quantities related to force? (That is to say, if you apply a changing force

to the cart, will the velocity or acceleration change in the same way as the force?) Explain.

2. To test your predictions, open the experiment file called **Motion and Force (L03A2-1)**. This will set up velocity, force, and acceleration axes with a convenient time scale of 5 s, as shown below. Be sure that the cart is always further than the minimum specified distance from the motion detector.



3. **Zero** the force probe. Then grasp the force probe hook and **begin graphing**. When you hear the clicks, pull the cart quickly away from the motion detector and stop it quickly. Wait a second and then push it quickly back toward the motion detector and again stop it quickly. Try to get sudden starts and stops, and to pull and push the force probe hook along a straight line parallel to the ramp. *Do not twist the hook. Be sure that the cart never gets too close to the motion detector. Be sure your hand and body are out of the way of the motion detector.*
4. Carefully sketch your graphs on the axes above, or **print** them and affix the graphs over the axes.

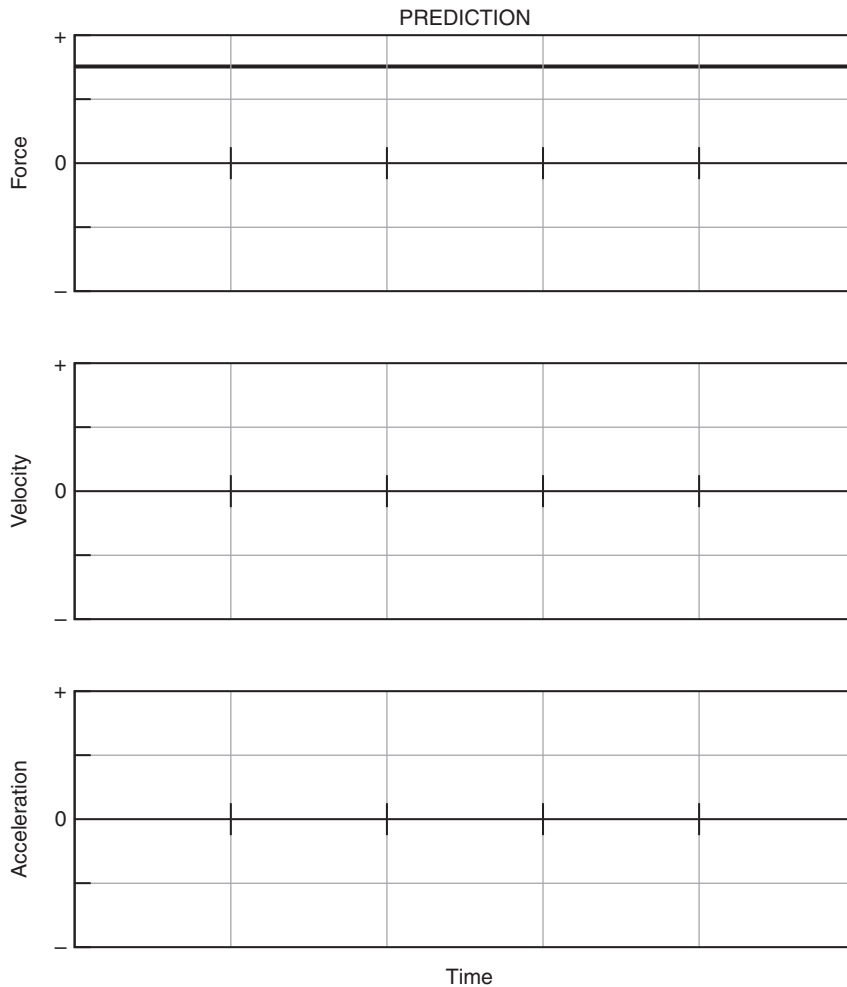
Question 2-1: Does either graph—velocity or acceleration—resemble the force graph? Which one? Explain how you reached this conclusion.

Question 2-2: Based on your observations, does it appear that there is a mathematical relationship between either applied force and velocity, applied force and acceleration, both, or neither? Explain.

Activity 2-2: Speeding Up Again

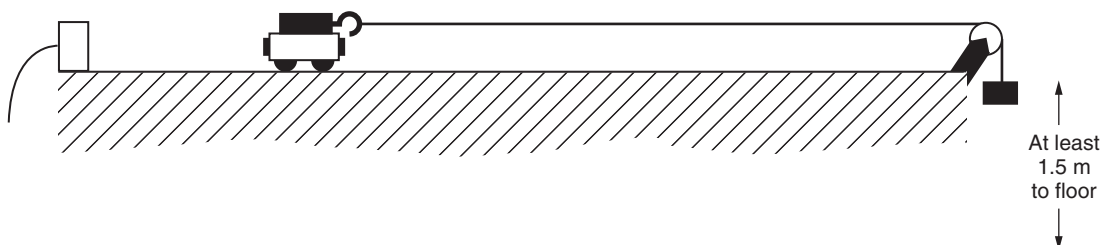
You have seen in the previous activity that force and acceleration seem to be related. But just what is the relationship between force and acceleration?

Prediction 2-2: Suppose that you have a cart with very little friction and you pull this cart with a constant force as shown below on the force–time graph. Sketch on the axes below your predictions of the velocity–time and acceleration–time graphs of the cart’s motion.



Describe in words the predicted shape of the velocity vs. time and acceleration vs. time graphs that you sketched.

1. Test your predictions. Set up the ramp, pulley, cart, string, motion detector, and force probe as shown below. The cart should be the same mass as before (about 1 kg).



Be sure that the cart's friction is minimum. (If the cart has a friction pad, it should be raised so it doesn't contact the ramp.)

2. Prepare to graph velocity, acceleration, and force. Open the experiment file called **Speeding Up Again (L03A2-2)** to display the velocity, acceleration, and force axes that follow.
3. It is important to choose the amount of the falling mass so the cart doesn't move too fast to observe the motion. Experiment with different hanging masses until you can get the cart to move across the ramp in about 2–3 s after the mass is released.

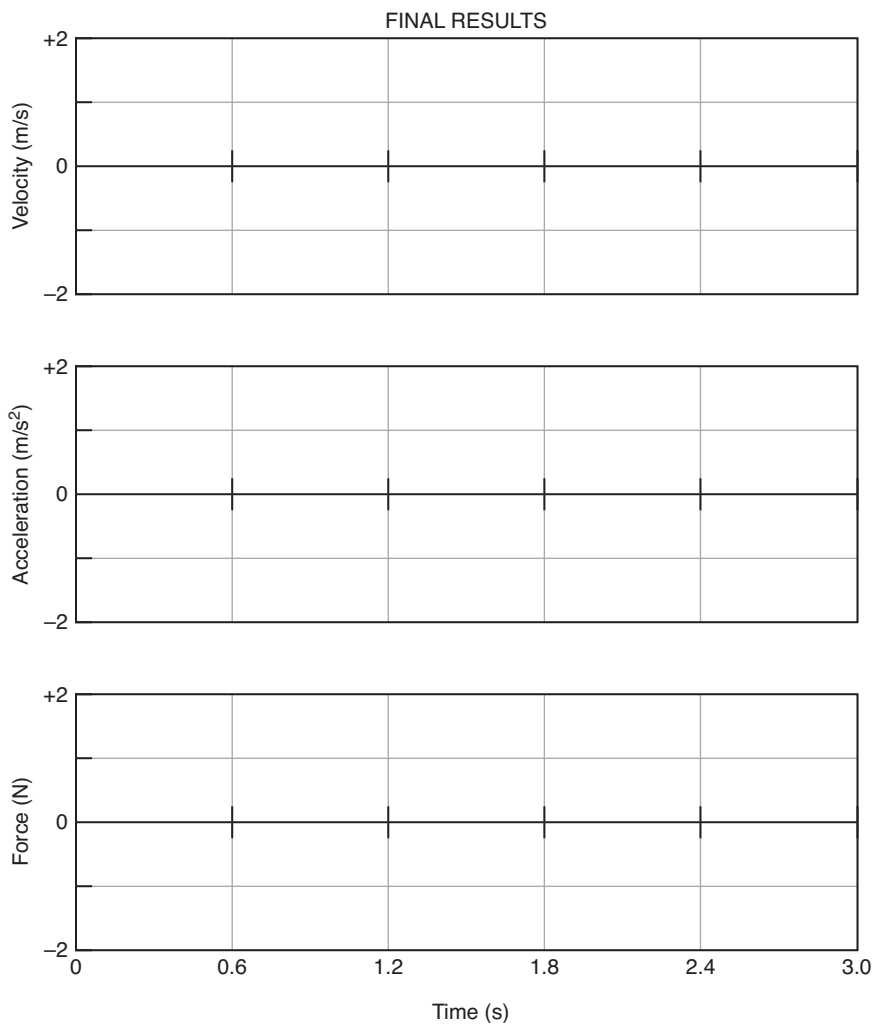
Record the hanging mass that you decided to use: _____

Also test to be sure that the motion detector sees the cart during its complete motion. *Remember that the back of the cart must always be further than the minimum specified distance from the motion detector.*

4. **Zero** the force probe with the string hanging loosely so that no force is applied to the probe.
5. **Begin graphing.** Release the cart after you hear the clicks of the motion detector. *Be sure that the cable from the force probe is not seen by the motion detector, and that it doesn't drag or pull the cart.*

Repeat until you get good graphs in which the cart is seen by the motion detector over its whole motion.

6. Transfer your data so that the graphs will be **persistently displayed on the screen.**
7. If necessary, **adjust the axes** to display the graphs more clearly. Sketch the actual velocity, acceleration, and force graphs on the axes that follow, or **print** the graphs and affix them over the axes. Draw smooth graphs; don't worry about small bumps.



Questions 2-3: After the cart is moving, is the force that is applied to the cart by the string constant, increasing, or decreasing? Explain based on your graph.

Question 2-4: How does the acceleration graph vary in time? Does this agree with your prediction? Does a constant applied force produce a constant acceleration?

Question 2-5: How does the velocity graph vary in time? Does this agree with your prediction? What kind of change in velocity corresponds to a constant applied force?

Activity 2-3: Acceleration from Different Forces

In the previous activity you examined the motion of a cart with a constant force applied to it. But what is the relationship between acceleration and force? If you apply a larger force to the same cart (while the mass of the cart is not changed) how will the acceleration change? In this activity you will try to answer these questions by applying different forces to the cart, and measuring the corresponding accelerations.

If you accelerate the same cart with two other different forces, you will then have three data points—enough data to plot a graph of acceleration vs. force. You can then find the mathematical relationship between acceleration and force (with the mass of the cart kept constant).

Prediction 2-3: Suppose you pulled the cart with a force about twice as large as before. What would happen to the acceleration of the cart? Explain.

1. Test your prediction. Keep the graphs from Activity 2-2 **persistently displayed on the screen.**
2. Accelerate the cart with a larger force than before. To produce a larger force, hang a mass about two times as large as in the previous activity.
Record the hanging mass: _____
3. Graph force, velocity, and acceleration as before. *Don't forget to zero the force probe with nothing attached to the hook right before graphing.*
4. Sketch your graphs as well as the graphs from Activity 2-2 on the axes below, or **print** out the graphs and affix them over the axes.

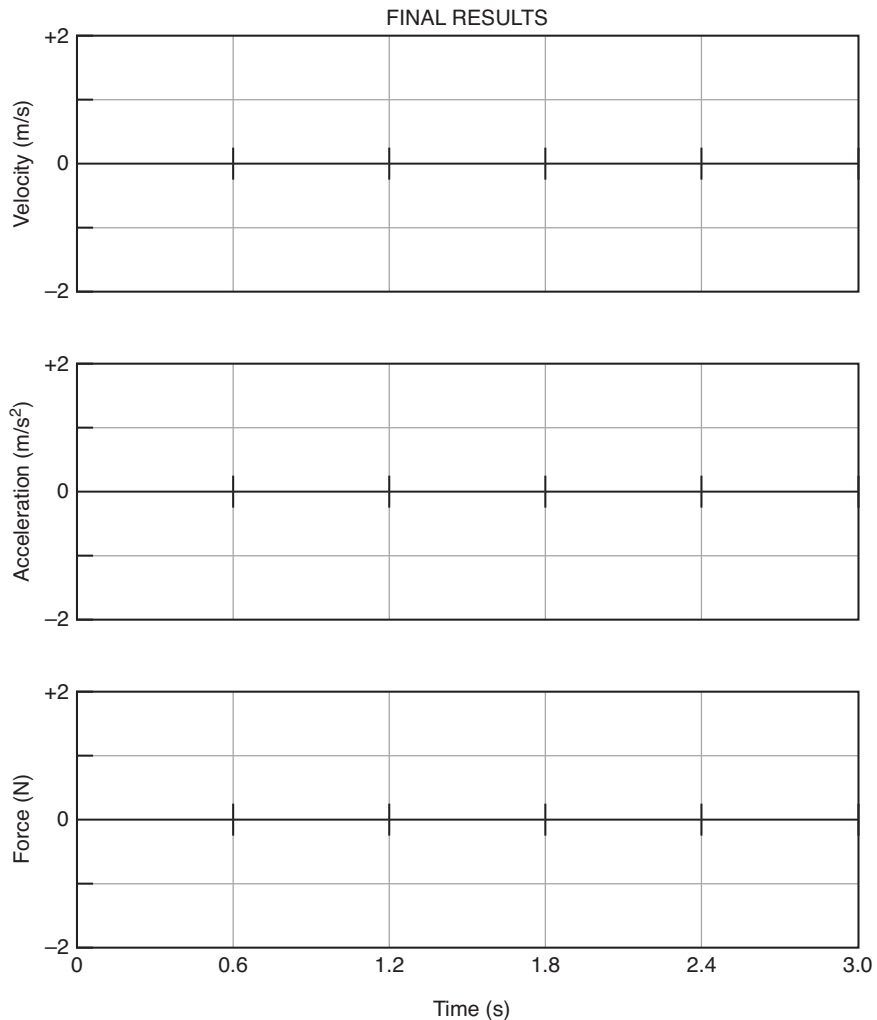


Table 3-1

	Average force (N)	Average acceleration (m/s^2)
Activity 2-2		
Activity 2-3		

5. Use the **statistics feature** of the software to measure the average force and average acceleration for the cart for this activity and Activity 2-2, and record your measured values in Table 3-1. *Find the mean values only during the time intervals when the force and acceleration are nearly constant.*

Question 2-6: How did the force applied to the cart compare to that with the smaller force in Activity 2-2?

Question 2-7: How did the acceleration of the cart compare to that caused by the smaller force in Activity 2-2? Did this agree with your prediction? Explain.

6. Accelerate the cart with a force roughly midway between the other two forces you applied. Use a hanging mass about midway between those used before.
Record the mass: _____
7. Graph velocity, acceleration, and force. Sketch the graphs on the previous axes, or **print** and affix them.
8. Find the mean acceleration and force, as before, and record the values in the bottom row of Table 3-1.

If you have time, carry out the following Extension to get more data for the acceleration vs. force graph you will make in the next activity.

Extension 2-4: More Acceleration vs. Force Data

Gather data for average acceleration and average force for several other forces applied to the same cart. Fill in the remaining rows in Table 3-1.

Activity 2-5: Relationship Between Acceleration and Force

In this activity you will find the mathematical relationship between acceleration and force.

1. Use the **graphing routine** in the software to plot a graph of acceleration vs. force from the data in Table 3-1. To plot the graph load the experiment file

called **Acceleration vs. Force (L03A2-5)**, and **enter** your data in the table. You may wish to **adjust the graph axes**, after all of the data are entered, to better display the data.

2. Use the **fit routine** to determine the mathematical relationship between the acceleration of the cart and the force applied to the cart as displayed on your graph.
3. **Print** your graph along with the fit equation and affix it in the space below.

Question 2-8: Does there appear to be a simple mathematical relationship between the acceleration of a cart (with fixed mass and negligible friction) and the force applied to the cart (measured by the force probe mounted on the cart)? Write down the equation you found and describe the mathematical relationship in words.

Question 2-9: If you increased the force applied to the cart by a factor of 10, how would you expect the acceleration to change? How would you expect the acceleration–time graph of the cart’s motion to change? Explain based on your graphs.

Question 2-10: If you increased the force applied to the cart by a factor of 10, how would you expect the velocity–time graph of the cart’s motion to change? Explain based on your graphs.

Comment: The mathematical relationship that you have been examining between the acceleration of the cart and the applied force is known as *Newton’s second law*. In words, when there is only one force acting on an object, the force is equal to the mass of the object times its acceleration.

HOMEWORK FOR LAB 3: FORCE AND MOTION

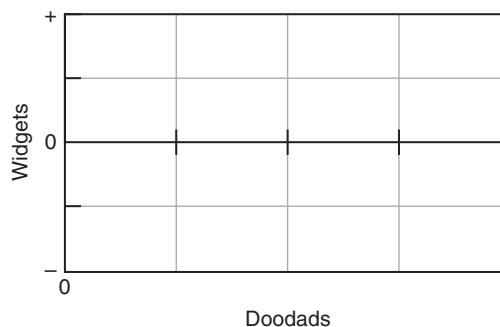
1. You are given 10 identical springs. Describe how you would develop a scale of force (i.e., a means of producing repeatable forces of a variety of sizes) using these springs.

2. Describe how you would use an uncalibrated force probe and the springs in Question 1 to develop a quantitative scale of force. How could you measure forces that do not correspond to exact numbers of stretched springs?

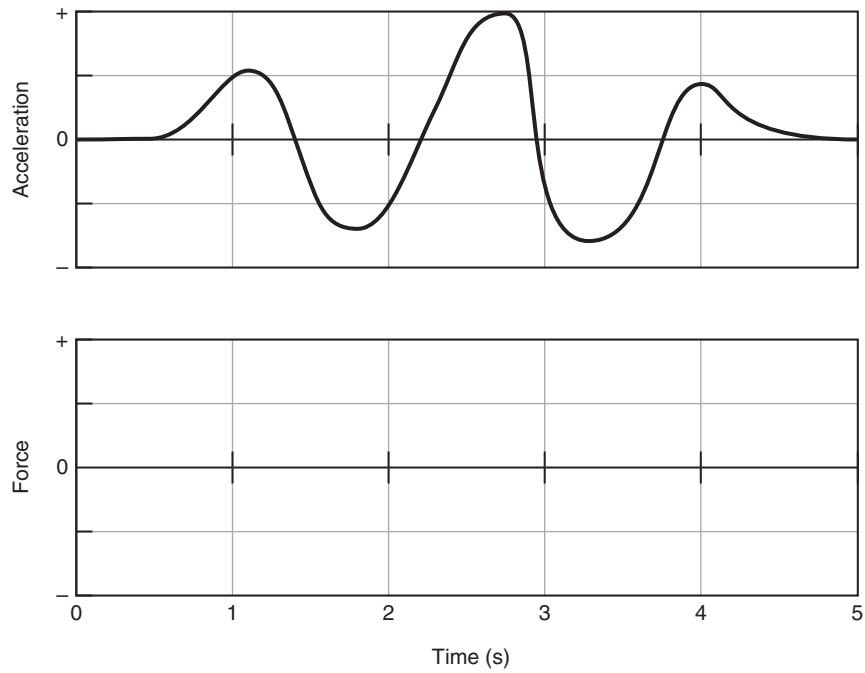
3. What is meant by a proportional relationship? Is this the same as a linear relationship? Explain.

4. Given the table of data below for widgets and doodads, how would you determine if the relationship between widgets and doodads is a proportional one? Sketch on the axes to the right of the table what the graph would look like if widgets are proportional to doodads.

Widgets	Doodads
0.0	0.0
150.5	10.0
305.0	20.0
442.7	30.0
601.3	40.0

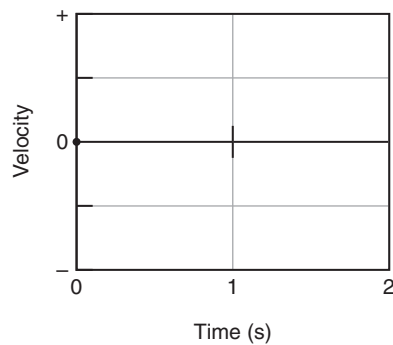


5. A force is applied that makes an object move with the acceleration shown below. Assuming that friction is negligible, sketch a graph of the force on the object as a function of time on the axes below.

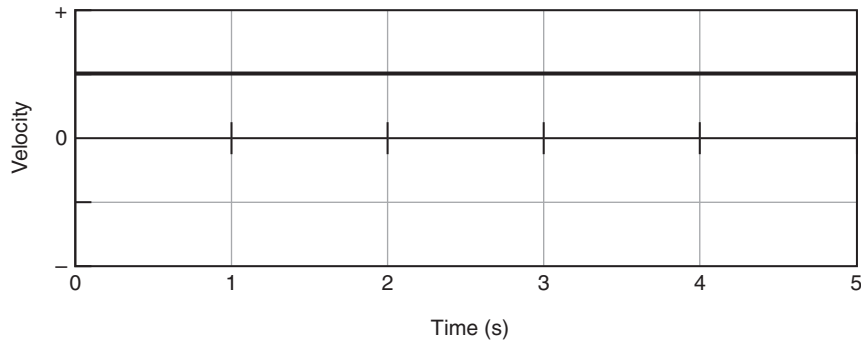


Explain your answer:

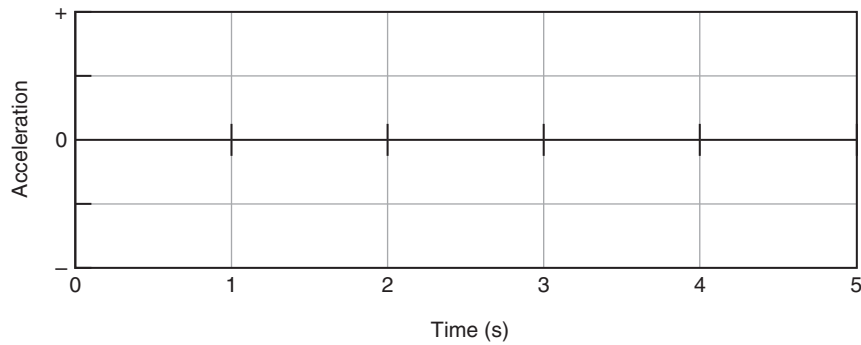
6. Assuming that the object starts at rest, roughly sketch a possible velocity–time graph for the object in Question 5 for the first 2 sec on the axes below.



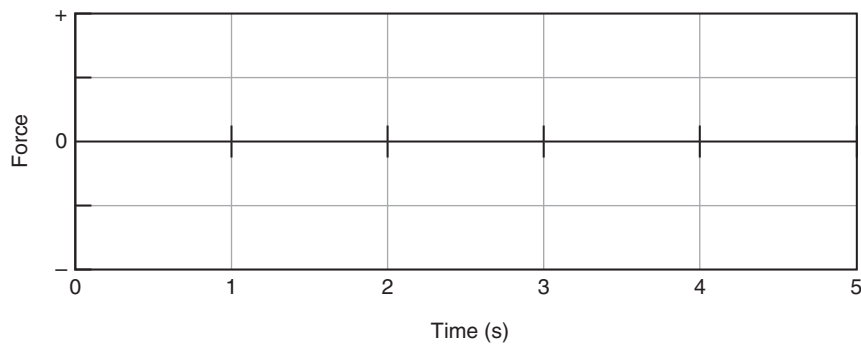
7. A cart can move along a horizontal line (the + position axis). It moves with the velocity shown below.



Sketch the acceleration-time graph of the cart's motion on the axes below.



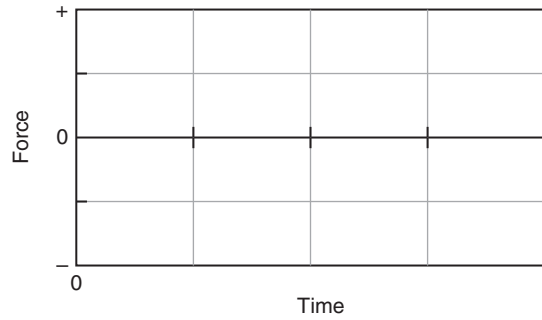
Assuming that friction is so small that it can be neglected, sketch on the axes below the force that must act on the cart vs. time to keep it moving with this velocity and acceleration.



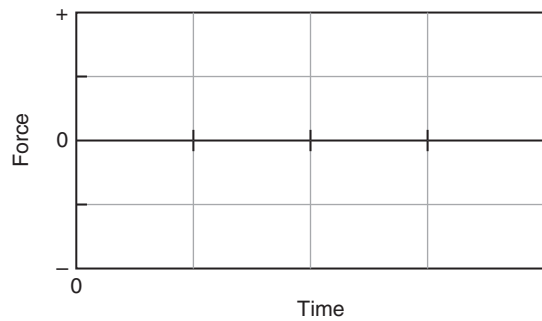
Explain both of your graphs.

Questions 8–10 refer to an object that can move in either direction along a horizontal line (the + position axis). Assume that friction is so small that it can be neglected. Sketch the shape of the graph of the force applied to the object that would cause the motion described to continue.

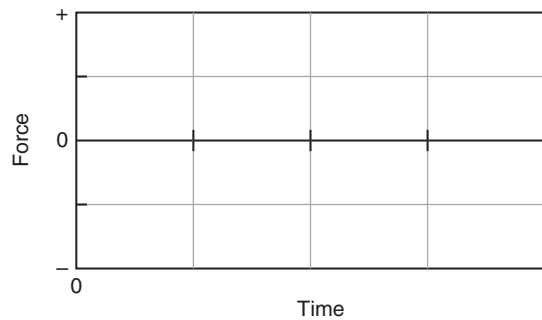
8. The object moves away from the origin with a constant velocity.



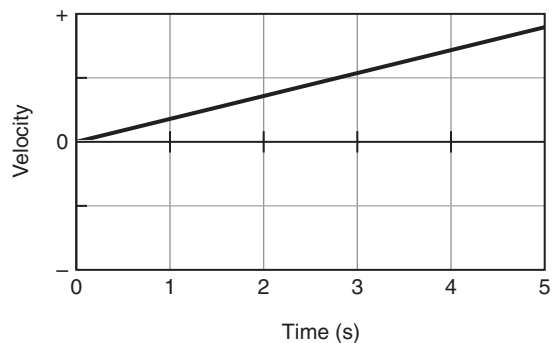
9. The object moves toward the origin with a constant velocity.



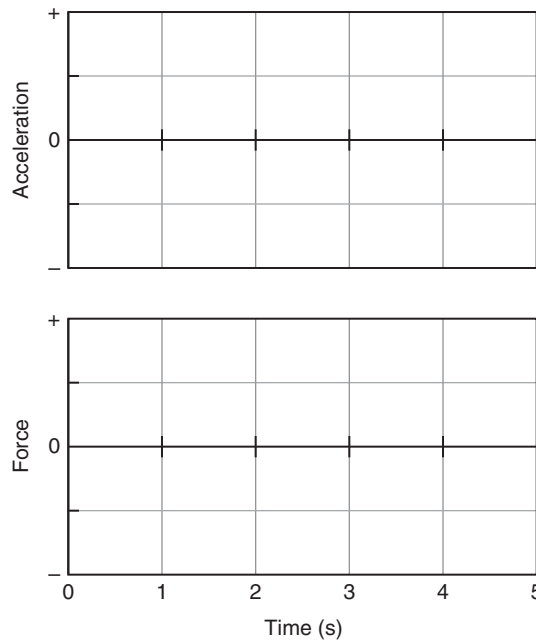
10. The object moves away from the origin with a steadily increasing velocity (a constant acceleration).



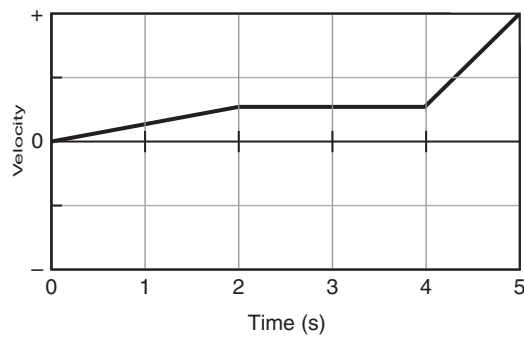
Questions 11 and 12 refer to an object that can move along a horizontal line (the + position axis). Assume that friction is so small that it can be ignored. The object's velocity–time graph is shown on the right.



11. Sketch the shapes of the acceleration–time and force–time graphs on the axes below.



12. Suppose that the force applied to the object were twice as large. Sketch with dashed lines on the same axes above the force, acceleration, and velocity vs. time.
13. An object can move along a horizontal line (the + position axis). Assume that friction is so small that it can be ignored. The object's velocity–time graph is shown below.



Sketch the shapes of the acceleration-time and force-time graphs on the axes below.

