Chapter 10

Vibrational Motion

10.1 Observations of vibrational motion

OALG 10.1.1 Observe and find a pattern

Equipment: Two small ~200-g objects, a soft spring (if available), piece of string.

For this activity, you will need a soft spring. If you do not have one, a rubber band can be used too. In addition, find some string (dental floss will work) and a couple of small objects to attach to the string and to the spring. Conduct the following two experiments and describe common patterns concerning the behavior of the hanging object.

a. Perform the experiments and record your observations.

Experiment 1: Tie a string to a small object and let the object hang freely. Then, pull the object to the side and release it. Record your observations.

Experiment 2: Hang another object from the spring (or the rubber band), pull the object down, and release it. Record your observations.

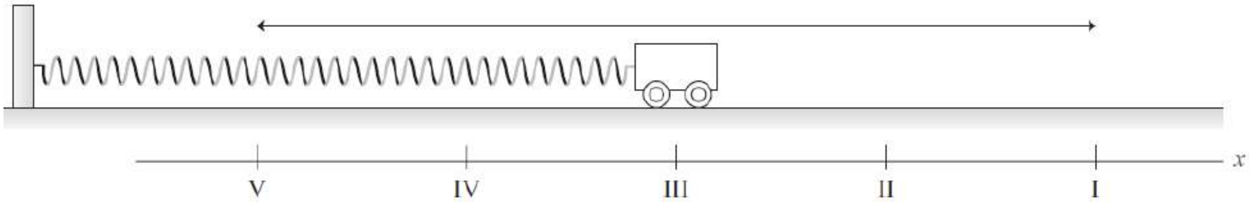
b. Identify patterns common to both experiments.

c. Compare and contrast the motions of the objects in these experiments with the motion of objects at constant speed or at constant acceleration.

OALG 10.1.2 Represent and reason

The cart in the figure below is attached to a light spring that can stretch *and* compress equally well. The cart and spring rest on a low-friction horizontal surface. The cart is shown at rest and not accelerating at position III. The cart is pulled to position I (by stretching the spring) and then released. The cart moves to position V, where it then reverses direction and returns again to position I. This motion then repeats.

Observe the cart in the video https://youtu.be/1bWGVC2-YSg and represent the cart's motion with motion diagrams and force diagrams, between each of the points indicated in the table that follows.



Draw a motion diagram for the motion between points I–III, while the cart is moving left.	Draw a motion diagram for motion between points III–V, cart moving left.	Draw a motion diagram for motion between points V-III, cart moving right.	Draw a motion diagram for motion between points III-I, cart moving right.
Draw a force diagram for the cart while it is at point I and moving left.	Draw a force diagram for point III, cart moving left.	Draw a force diagram for point V, cart moving left.	Draw a force diagram for point II, cart moving left.
Draw a force diagram for point I, cart moving right.	Draw a force diagram for point III, cart moving right.	Draw a force diagram for point V, cart moving right.	Draw a force diagram for point II, cart moving right.

a. Do the force diagrams depend on whether the cart was moving left or right? Explain.

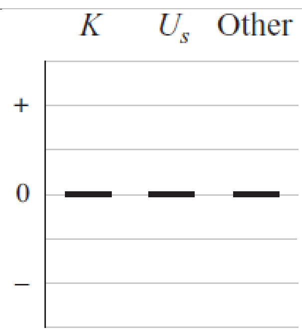
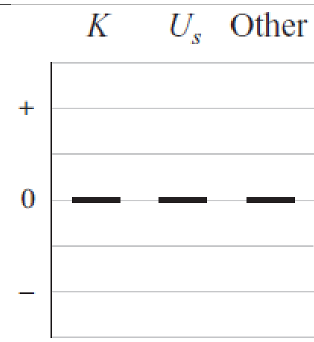
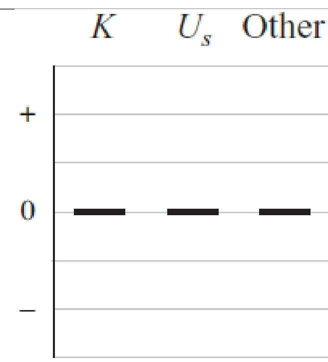
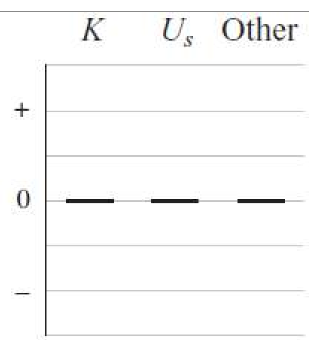
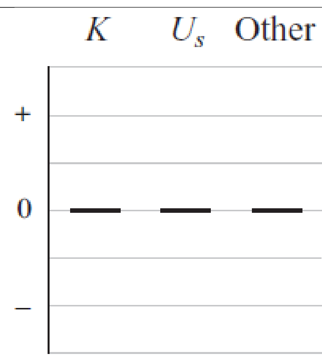
b. Are the force descriptions consistent with the motion descriptions? For example, is the net horizontal force in the same direction as the acceleration? Give several specific examples.

c. At each position, compare the direction of the force exerted by the spring on the cart and the cart's displacement from equilibrium when at that position.

d. Summarize the patterns in the direction of the sum of the forces exerted on the cart and displacement of the cart. Compare the patterns you identified with the patterns in Observational Experiment Table 10.1 on page 285 in the textbook and patterns 1 and 2 on page 287. Make sure you read and interrogate the definitions of the equilibrium position, restoring force, and amplitude.

OALG 10.1.3 Represent and reason

a. Construct five qualitative work–energy bar charts for the cart–spring system described in Activity 10.1.2 at the points described in the table that follows.

Construct a work–energy bar chart for point V.	**Construct a work–energy bar chart for point IV.**	**Construct a work–energy bar chart for point III.**
		
Construct a work–energy bar chart for point II.	**Construct a work–energy bar chart for point I.**	
		

b. Do the charts depend on whether the cart is moving left or right when at a particular position? Explain.

c. Identify patterns in the energy conversions during this activity's example of vibrational motion. Compare those to the patterns identified in Observational Experiment Table 10.2 on page 286 in the textbook and pattern 3 on page 287.

d. How would the charts change if the surface had considerable friction? Explain.

OALG 10.1.4 Reason and explain

Summarize the results of Activities 10.1.3–10.1.4 to describe and explain the motion of the cart. The description should include your observations, and the explanations should include your reasoning based on force and energy analyses for the observed phenomena.

OALG 10.1.5 Read and interrogate

Read and interrogate the sub-section "Period and frequency" in Section 10.1 in the textbook and answer Review Question 10.1.

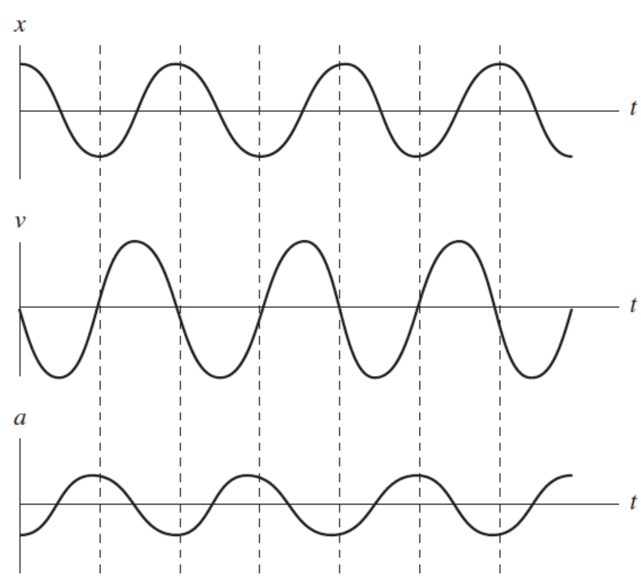
OALG 10.1.6 Practice

Answer Questions 1-3 on page 309 in the textbook and solve Problems 2 and 4 on page 310.

10.2 Kinematics of vibrational motion

OALG 10.2.1 Observe and find a pattern

Suppose that when the cart in Activity 10.1.3 was vibrating at the end of the spring, you used a motion detector to record the cart's motion. The resulting graphs of position-versus-time, velocity-versus-time, and acceleration-versus-time are shown below.



Examine the graphs carefully and answer the questions that follow.

a. Are the position and velocity graphs consistent with your motion diagrams in Activity 10.1.2? Compare the $x(t)$ graph with the $v(t)$ graph at times when $x(t)$ is a maximum, when $x(t)=0$, and when $x(t)$ is a minimum. Explain how the graphs are consistent with each other and with the motion diagrams you drew.

b. Recall that $v = \Delta x / \Delta t$. Is the shape of the velocity-versus-time graph consistent with this mathematical definition and with the position-versus-time graph? Compare the slope of $x(t)$ with the values of v at the maximum, minimum, and zero points. Explain.

c. Is the direction and magnitude of the acceleration in the $a(t)$ graph consistent with the direction and magnitude of the restoring force in the force diagrams in Activity 10.1.3? Compare several points and explain.

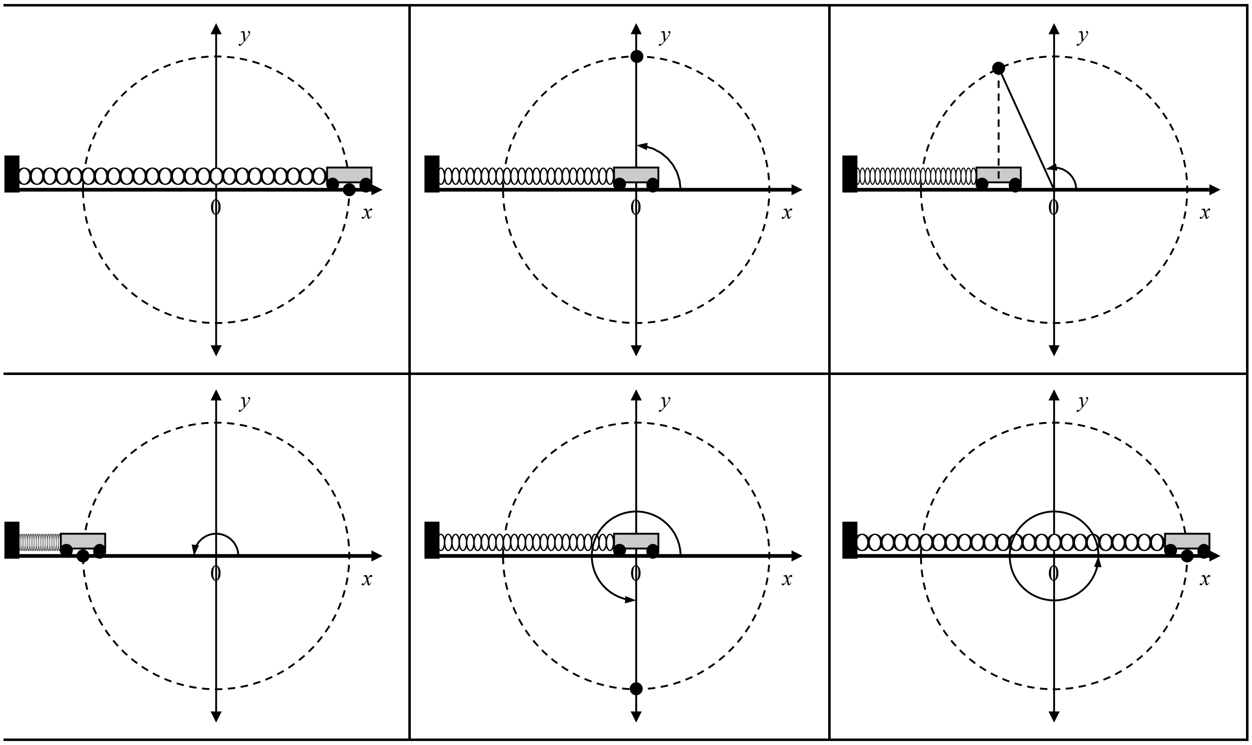
d. Describe the relationship between the position-versus-time graph and the acceleration-versus-time graph. Explain why they mirror each other. Think about Newton's second law and the mathematical representation for the force that the spring exerts on the cart ($F_{\text{S on C},x} = -kx$).

e. Decide what mathematical function can be used to describe the position of the cart as a function of time.

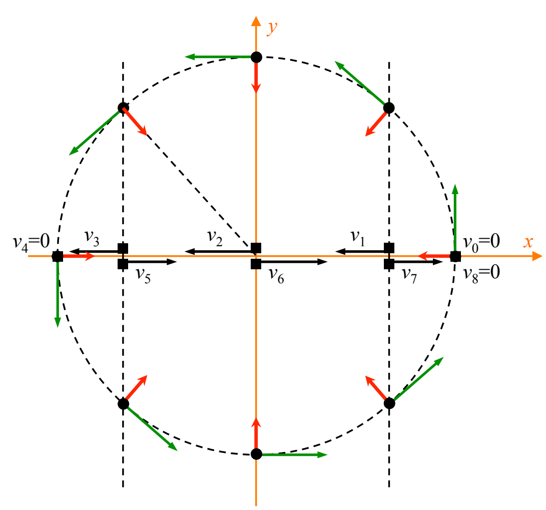
f. Period is a physical quantity that characterizes the time interval for one complete vibration. In each of the three graphs at the beginning of this activity, indicate the period of the vibration.

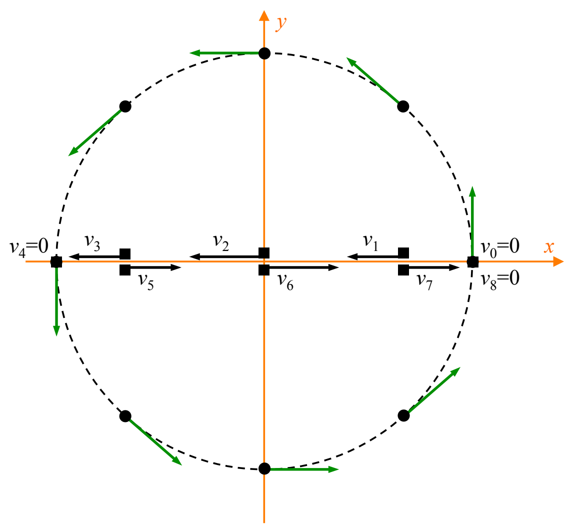
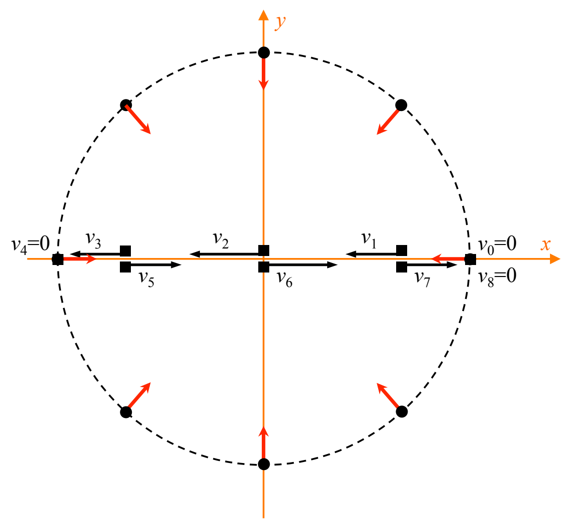
OALG 10.2.2 Observe and find a pattern

In the series of snapshots shown below, the motion of the cart on a spring from Activity 10.1.3 is shown in relation to an object (represented by the black dot) that is moving at constant speed in a circle of radius A with a period of T. Describe what you see in these six snapshots. Is there a pattern? What seems to be the relationship between the motion of the black dot and the motion of the cart?



OALG 10.2.3 Represent and reason

An object (represented by the black dot in the figure at right) is moving around a circle at a constant rotational speed with a period T. The radius of the circle is A. The motion diagram of the cart on the spring is shown by the squares along the x-axis. The green arrows represent the tangential velocity of the object at the points shown. The red arrows represent the radial acceleration of the object at the points shown.	
At each point where the dot is located in the figure below, draw the x-component of its tangential velocity and use that to write a	At each point where the dot is located in the figure below, draw the x-component of its radial acceleration and write a mathematical representation for a_x in terms of A, T, and the

<table>
<tr><td>mathematical representation for v_x in terms of A, T, and the angle that the dot is located.</td><td>angle that the dot is located.</td></tr>
<tr><td>
</td><td>
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OALG 10.2.4 Reason

a. Use your results from Activity 10.2.3 to write mathematical representations for $x(t)$, $v(t)$, and $a(t)$ as cosine or sine functions of time. (In your expressions, try to use the quantities amplitude A and period T.) How do you know whether the representations you wrote make sense?

b. Compare and contrast your representations with Equations 10.2; 10.3 and 10.4 on pages 290-291 in the textbook.

OALG 10.2.5 Represent and reason

A 2.0-kg cart attached to a horizontal spring vibrates on a low-friction track (similar to the situation shown in Activity 10.1.3). The cart's displacement-versus-time is described by:

$$x = (0.20\text{ m})\sin\left[\left(\frac{2\pi}{2.0\text{ s}}\right)t\right]$$

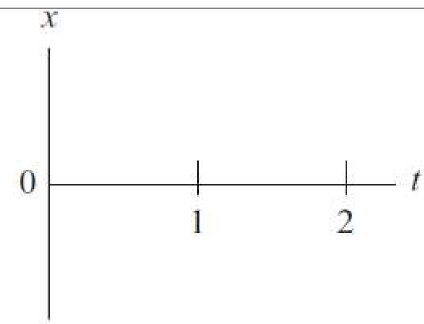
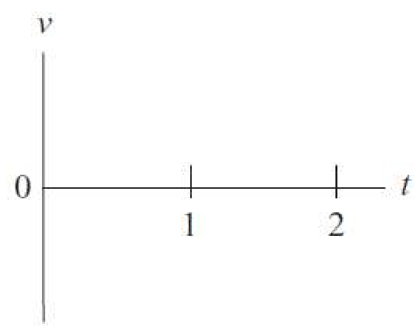
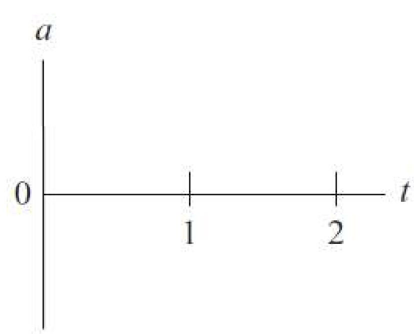
The positive direction of the x-axis is to the right. Determine the cart's position at $t = 0$, $t = 0.5$ s, $t = 1.0$ s, and $t = 1.5$ s. What is special about the chosen times? (*Hint*: What fraction of the period is 0.5 s, 1.0 s, and 1.5 s?) If you are having trouble, use Quantitative Exercise 10.2 on page 291 for help.

OALG 10.2.6 Represent and reason

A 2.0-kg cart attached to a spring undergoes simple harmonic motion so that its displacement-versus-time is described by:

$$x = (0.20\ \text{m})\sin\left[\left(\frac{2\pi}{2.0\ \text{s}}\right)t\right]$$

What is the meaning of each number in the function above? Determine the period and the amplitude of the motion. Then plot graphs of the cart's position, velocity, and acceleration as a function of time, using the axes given below as a guide.

Construct a position-versus-time graph.	
Construct a velocity-versus-time graph.	
Construct an acceleration-versus-time graph.	

OALG 10.2.7 Apply

Watch the high-speed video of a hovering hummingbird (recorded at 400 frames per second) [https://mediaplayer.pearsoncmg.com/assets/_frames.true/sci-phys-egv2e-alg-10-2-5] and answer the following questions:

a. Estimate the frequency of the bird's wing flapping. Describe how you minimized the uncertainty.

b. The hummingbird in the video is 10 cm long (tail to beak). Use your knowledge of vibrational motion to estimate the maximum speed of the tips of the hummingbird's wings. What is the uncertainty in your value? Indicate any assumptions that you made. Describe the positions that the wings are in when the magnitude of the velocity reaches maximum value.

c. Estimate the maximum acceleration of the tips of the hummingbird's wings. Describe the positions that the wings are in when the magnitude of the acceleration reaches maximum value.

OALG 10.2.8 Read and interrogate

Read and interrogate Section 10.2 in the textbook and answer Review Question 10.2.

OALG 10.2.9 Practice

Answer Questions 1and 7 on page 309 in the textbook and solve Problems 5, 9, and 11 on page 310.

10.3 Dynamics of simple harmonic motion

OALG 10.3.1 Explain

Examine the graphs in Activity 10.2.1 and answer the following questions:

a. Are the direction and magnitude of the acceleration consistent with the direction and magnitude of the restoring force? Explain.

b. Describe the relationship between the position-versus-time graph and the acceleration-versus time graph. Explain why they mirror each other. Think about Newton's second law and the expression for the force that the spring exerts on the cart: $F_{\text{S on C}, x} = -k\Delta x$.

If you are having trouble, read and interrogate the sub-section "Forces and acceleration" in Section 10.3 in the textbook.

c. Draw a graph $F_{\text{S on C},x}$ versus t.

OALG 10.3.2 Derive

The goal of this activity is to help you derive an expression for the period of the cart's vibration at the end of the spring shown in Activity 10.1.3. Begin the derivation by answering two questions (part **a.** and part **b.**).

a. What physical quantities might affect the period?

b. Describe experiments that you could perform to decide whether these quantities do in fact affect the period.

Now we move to the actual step-by-step derivation (parts **c.**–**e.**).

c. Write down Newton's second law for the cart ($a = \ldots$)

d. Substitute your expressions for $x(t)$ and $a(t)$ into the Newton's second law equation you came up with in Activity 10.2.4.

e. Come up with an expression for T that is necessary for the mathematical representation in part **d.** to be true.

f. Compare your expression with Equation 10.7 on page 294 in the textbook.

OALG 10.3.3 Test an idea

Equipment: a spring or a rubber band with an object to hang on it or a rubber band, a stopwatch, a ruler.

In the previous activity, you found that the period of an object vibrating on a spring does not depend on the amplitude of vibrations.

a. Explain whether this finding makes sense to you. Shouldn't a larger amplitude lead to a longer time for an object to come back to the equilibrium position?

b. Design an experiment to test whether the hypothesis that the amplitude of vibrations does not affect the period applies to a system of an object attached to a rubber band.

c. Write a brief outline of the experimental procedure that you will use to test the hypothesis that the period of vibrations of an object attached to a rubber band does not depend on the amplitude of vibrations. Include a labeled sketch.

d. Conduct the experiment and record the data that you collected. What are the uncertainties in your data?

e. What is your judgment about the hypothesis?

OALG 10.3.4 Represent and reason

A 2.0-kg cart attached to a spring undergoes simple harmonic motion so that its displacement-versus-time is described by:

$$x = (0.20\text{ m})\sin\left[\left(\frac{2\pi}{2.0\text{ s}}\right)t\right]$$

a. Draw a motion diagram for one cycle of the cart's motion.

b. Draw a force diagram for the cart at the times indicated as follows: $t = 0$, $t = T/4$, $t = T/2$, $t = 3T/4$, $t = T$.

OALG 10.3.5 Read and interrogate

Read and interrogate Section 10.3 in the textbook and answer Review Question 10.3.

OALG 10.3.6 Practice

Answer Question 9 on page 309 in the textbook and solve Problems 15, 18, and 19 on page 310.

10.4 Energy of vibrational systems

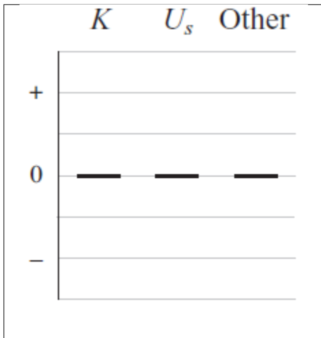
OALG 10.4.1 Represent and reason

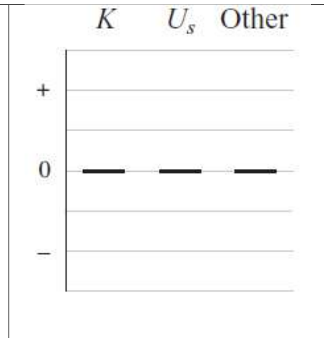
A 2.0-kg cart attached to a spring undergoes simple harmonic motion so that its displacement-versus-time is described by:

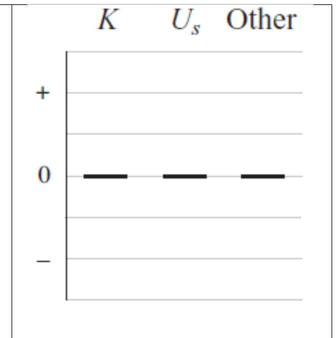
$$x = (0.20\text{ m})\sin\left[\left(\frac{2\pi}{2.0\text{ s}}\right)t\right]$$

a. Construct qualitative energy bar charts for the cart–spring system at the times indicated in the table that follows.

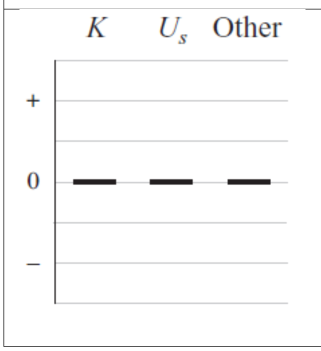
$t = 0$	$t = T/4$	$t = T/2$



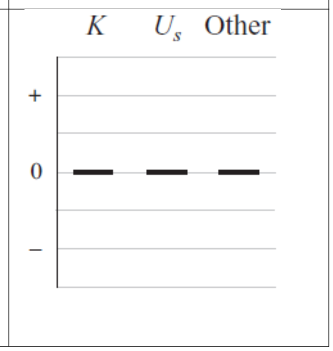




$t = 3T/4$



$t = T$



b. Come up with general expressions for the kinetic energy and elastic potential energy of a cart & spring system if it is oscillating with an amplitude A, the cart has a mass m, and the spring has a spring constant k.

c. Come up with a general expression for the *total* energy of the cart & spring system at any point if it is oscillating with an amplitude A, the cart has a mass m, and the spring has a spring constant k.

OALG 10.4.2 Represent and reason

A 2.0-kg cart attached to a spring undergoes simple harmonic motion on a low-friction surface. Its displacement-versus-time is described by:

$$x = (0.20\text{ m})\sin\left[\left(\frac{2\pi}{2.0\text{ s}}\right)t\right]$$

a. Determine the period and the amplitude of the motion.

b. Determine the spring constant of the spring to which the cart is attached.

c. Determine the maximum elastic potential energy of the system.

d. Determine the maximum speed of the cart. At which position(s) does this maximum v occur?

e. Write a general mathematical expression for the velocity as a function of time using the given numbers.

f. Determine the maximum acceleration of the cart. At which position(s) does this maximum *a* occur?

g. Write a general mathematical expression for the acceleration as a function of time using the given numbers.

OALG 10.4.3 Analyze

Jumper is a simple toy that consists of a head and a foot that are connected by a steel spring. Below the head is a suction cup, which is fixed on the head (see the photo on the right). When you push on the Jumper's head, the spring compresses and the suction cup sticks to the foot. After some time, the suction cup detaches from the foot and the spring quickly pushes the head and foot apart. If you put the Jumper on the table, it can jump more than one meter high, depending on the design.

We modified the Jumper shown in the photo by gluing a square piece of cardboard onto its head. This also allowed us to launch the Jumper in the head-down position. The total mass of the Jumper is 6.0 g. Note that in each experiment, the spring was compressed an equal distance, 1.5 cm.

a. Carefully watch the video at [https://mediaplayer.pearsoncmg.com/assets/_frames.true/sci-phys-egv2e-alg-10-4-4]. Explain why the Jumper that is launched in a head-down position reaches a smaller height than the Jumper that is launched in a head-up position. Focus on the motion of the individual parts of the Jumper.

b. When answering part **a.,** why was it not useful to model the Jumper as a point-like object? Suggest a better model for analyzing the Jumper.

c. Take the Jumper and Earth as a system. Let the initial state be the Jumper when it is resting while compressed on the table and the final state be when the head of the Jumper is at the 5-cm mark in the video. Represent the energy conversion in each experiment (launching in the head-up position and in the head-down position) by drawing work-energy bar charts. If you decide upon a model for the Jumper that is not point-like, use additional bar charts to for each part of the object.

d. Repeat part **c.** However, this time, choose the final state as the instant when the Jumper reaches the highest point above the table.

e. Estimate the spring constant of the steel spring that connects the Jumper's head and foot. Indicate any assumption that you made.

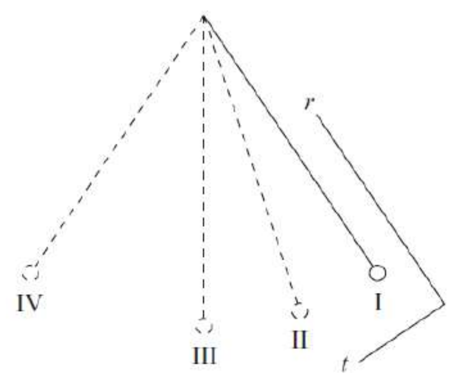
OALG 10.4.4 Practice

Answer Question 12 on page 309 in the textbook and solve Problems 27-29 on page 311.

10.5 The simple pendulum

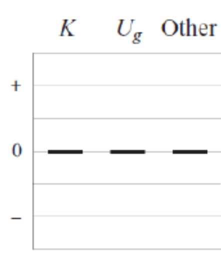
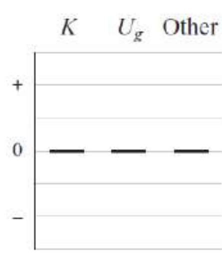
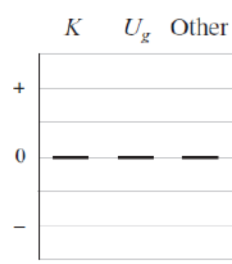
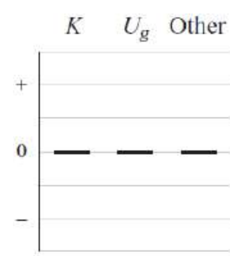
OALG 10.5.1 Represent and reason

You have a small bob on a long string (a pendulum). The pendulum bob swings back and forth, as shown in the figure below. It is released at position I and swings all the way to position IV before coming back. At each of the marked points in the figure, the coordinate system consists of an axis in the radial direction (*r*-axis) and a perpendicular axis in the tangential direction (*t*-axis). Disregard air resistance.



a. Complete the table that follows for the positions shown in the figure.

Use the graphical velocity method to estimate the direction of the bob's acceleration.	Position I	Position II	Position III	Position IV

Draw a force diagram for the bob.	Position I	Position II	Position III	Position IV
Draw the *r* - component of the sum of the forces and of the acceleration. Do they match?	Position I	Position II	Position III	Position IV
Draw the *t*- component of the sum of the forces and of the acceleration. Do they match?	Position I	Position II	Position III	Position IV
Construct an energy bar chart.	Position I 	Position II 	Position III 	Position IV 

b. Check your work with Figure 10.10 on page 297.

c. Is there a relationship between the *t*-component of the net force and the displacement of the bob from the equilibrium position? Explain.

c. Compare and contrast the patterns of the net force and acceleration of the vibrating pendulum bob to the net force and acceleration of the vibrating cart in Activity 10.1.3.

OALG 10.5.2 Test your ideas

Equipment: a set of objects of different mass, a string, and a ruler.

Design an experiment to test each relationship proposed below (some relationships may be incorrect).

For each relationship:

a. Describe the experiment and include a sketch.

b. List the controlled variables (i.e., what you keep constant).

c. Describe the procedure and the predictions that you make based on the relationship under test.

d. Perform the experiment and record the outcome.

e. Compare the outcome to the prediction and make a judgment concerning the relationship.

Relationships to test:

1. The period of vibration of a simple pendulum depends on the mass of the bob.

2 The period of vibration of a simple pendulum is directly proportional to the length of the string.

OALG 10.5.3 Observe and find a pattern

You have a pendulum consisting of a long string with a metal bob hanging at one end. You can vary the mass m of the metal bob, the length L of the string, and the amplitude A of its back-and-forth vibrations. You vary one of these three quantities at a time, measure the period of the pendulum, and then calculate the frequency (if needed). The data are shown in the table.

Bob mass (kg)	String length (m)	Amplitude (m)	Period (s)
1	1	0.05	2.00
2	1	0.05	2.00
3	1	0.05	2.00
1	2	0.05	2.80
1	3	0.05	3.45
1	4	0.05	4.00

1	1	0.07	2.00
1	1	0.10	2.00

a. Based on this data, decide what physical quantities affect the period. Decide which quantities do not affect the period. Explain. If some of your findings in this activity do not match your findings in Activity 10.5.2, reconcile.

b. Read and interrogate the sub-section "Deriving the period of a simple pendulum" on page 298 in the textbook to explain where the expression for the period of a *simple pendulum* (a small object vibrating with small amplitude on a long string)

$$T = 2\pi\sqrt{\frac{L}{g}}$$

where g is the free-fall acceleration, came from. Use the data in the table to decide whether the pendulum in the experiment can be considered a simple pendulum. Explain your decision.

OALG 10.5.4 Test your ideas

Equipment: a small object to attach to a string, a piece of string, a stopwatch and a ruler.

Assemble a pendulum with a string and an object (decide how you will affix the top of the string in your home). Use the relationship between the period and the length of the string for a simple pendulum to predict the period of its vibrations. Write your predicted value while taking experimental uncertainties into account. Then, perform the experiment and compare your prediction to the outcome. Remember that the amplitude of vibration should be small. Can your pendulum be considered a simple pendulum? Now, shorten the string considerably and repeat the procedure. Is the pendulum still behaving like a simple pendulum?

OALG 10.5.5 Practice

Answer Questions 15 and 19 on page 309 in the textbook and solve Problems 31, 33, and 39 on page 311.

10.6 Skills for analyzing processes involving vibrational motion

OALG 10.6.1 Multiple possibility problem

Solve the following problem using the problem solving strategy in the table below. Then, compare your solution to Example 10.7 in the textbook.

A long, light spring is hooked to a ceiling and hangs vertically. When we hang a 0.40-kg clay ball (ball 1) at the bottom end, the spring extends by 4.0 cm. A 0.20-kg clay ball (ball 2) rests on a table, 30 cm below the hanging clay ball. You kick ball 1 down from its equilibrium position (you give the ball an initial velocity). Determine the frequency of oscillations of the vibrating system. Note that if the two balls touch, they stick together.

Sketch and translate • Sketch the process described in the problem statement. Label known and unknown physical quantities. • Visualize the processes described in the problem statement. • Choose an object (or objects) as the system of interest. Depending on the process, you might need to analyze several systems.	
Simplify and diagram • Identify and evaluate assumptions and approximations. • Represent the process with force diagrams and/or work-energy bar charts if needed.	
Represent mathematically • If necessary, use kinematics equations to describe the changing motion of the object. • If necessary, use the force diagrams to apply the component form of Newton's second law or use the bar charts to apply work-energy principles. • If necessary, use the expressions for the period of an object attached to a spring or to a pendulum.	

Solve and evaluate • Solve for the unknowns. • Evaluate the solution—is it reasonable? • Consider the magnitude of the answer, its units, limiting cases, etc.	

OALG 10.6.2 Regular problem

An astronaut living on a space station is in a constant state of free fall—the only force exerted on her and on the space station is the gravitational force due to Earth. How can an astronaut determine her mass while on an extended stay in space? One method involves vibrational motion. An astronaut sits on a chair that vibrates horizontally at the end of a spring. A motion detector determines the amplitude of vibration and the speed of the chair as it passes through the equilibrium position. The spring has a 1200-N/m spring constant, the amplitude of vibration is 0.50 m, and the speed of the chair as it passes through equilibrium is 2.0 m/s. Using these data, find the combined mass of the chair and the astronaut.

OALG 10.6.3 Regular problem

A 0.20-kg arrow moving horizontally at 10 m/s hits a 0.40-kg clay ball hanging at the end of a 1.5-m-long string. The arrow embeds itself inside the clay ball, and the arrow and ball swing together in an arc up to some undetermined final height.

a. Determine the speed of the ball-arrow system immediately after the collision. If you are having trouble, consult Example 10.8 on page 302 in the textbook.

b. The ball with the arrow swings in an arc upward after the collision. Determine how high the ball will rise and whether the answer is reasonable.

c. Determine the frequency of the pendulum-like vibration of the ball–arrow system.

d. List the assumptions that you made.

OALG 10.6.4 Equation jeopardy

Mathematical representations describe two situations involving vibrational motion.

a. Sketch a situation that the representation(s) might describe. Label known quantities.

b. In words, write a problem for which the representation(s) lead to a solution.

Situation 1:

$$(1/2)(20{,}000\ \text{N/m})(0.20\ \text{m})^2 = (1/2)(100\ \text{kg})v^2 + (1/2)(20{,}000\ \text{N/m})(0.10\ \text{m})^2$$

Situation 2:

$$0.20\ \text{Hz} = (1/2\pi)\left[k/(100\ \text{kg})\right]^{1/2}$$

$$(1/2)k(0.40\ \text{m})^2 = (1/2)(100\ \text{kg})v_{\text{max}}{}^2$$

OALG 10.6.5 Design an application experiment

Equipment: stopwatch, small object, string, ruler.

Design an experiment using this equipment and your knowledge of a simple pendulum to measure the acceleration of free falling objects (g), in your room.

a. Describe the experiment in words.

b. Draw a labeled sketch of the apparatus.

c. Describe the mathematical procedure you will use to determine g.

d. List the physical quantities that you will measure and the quantities that you will calculate.

e. List sources of experimental uncertainties and ways to minimize them.

OALG 10.6.6 Pose a problem

Equipment: rubber band, a small object, stopwatch, meter stick.

Pose an experimental problem that you can solve using the equipment listed. Describe how you would solve the problem.

OALG 10.6.7 Practice

Solve Problems 45, 59, 70, and 71 on pages 311-313.

10.7 Including friction in vibrational motion

OALG 10.7.1 Observe and explain

Watch the video [https://mediaplayer.pearsoncmg.com/assets/_frames.true/sci-phys-egv2e-alg-10-7-1]. Use the video timer to compare the two pendulums quantitatively. Explain the differences in their motion. Draw energy bar charts for each experiment. What is the best system to choose for your analysis?

OALG 10.7.2 Read and interrogate

Read and interrogate Section 10.7 in the textbook and compare your experiments and findings with those in the textbook. Then, answer Review Question 10.7.

OALG 10.7.3 Practice

Solve Problems 49 and 50 on page 312.

10.8 Vibrational motion with an external driving force

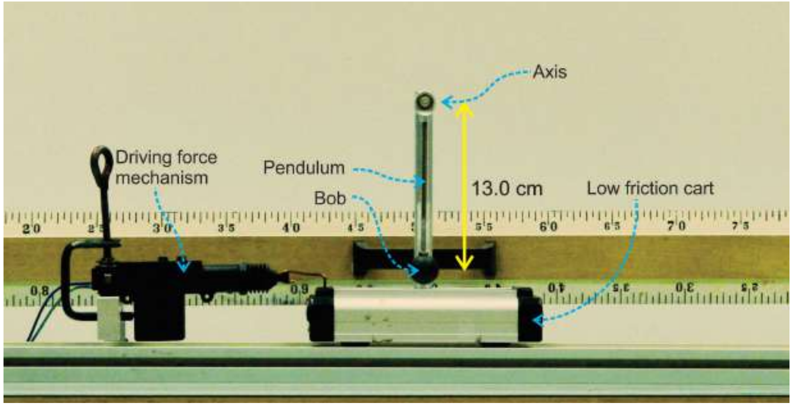
OALG 10.8.1 Observe and explain

Equipment: a swing.

Go outside and find a swing in a park. Start swinging and pay attention to how you need to move to increase the amplitude. Then, go home and use yourself and Earth as a system to analyze this process using work-energy bar charts. The initial state is when the swing is at rest at the bottom (before you start swinging) and the final state is when the swing is at either the top or bottom while moving with a maximum velocity for that specific swing. After you draw the bar charts, read and interrogate Observational Experiment Table 10.6 and compare and contrast your analysis with the analysis in this table. Note that the experiments described in the table are different from the ones you conducted.

OALG 10.8.2 Observe and analyze

[https://mediaplayer.pearsoncmg.com/assets/_frames.true/sci-phys-egv2e-alg-10-8-2].



Watch the video [https://mediaplayer.pearsoncmg.com/assets/_frames.true/sci-phys-egv2e-alg-10-8-2] and answer the following questions:

a. Explain the outcome of the experiment. How did the experimenter change the frequency of the vibrations of the cart?

b. What happened to the frequency of the pendulum? We know that the frequency of a simple pendulum depends only on its length; how can we reconcile our previous knowledge with the results this experiment?

c. Why did the amplitude of the vibrations of the pendulum change?

d. Use your knowledge of vibrational motion to estimate the length of the pendulum. What is the uncertainty in this value? Indicate any assumptions that you made.

e. Use the meter-stick in the video to estimate the length of the pendulum directly. How far away is the estimate from the value you estimated in part **d.**?

OALG 10.8.3 Read and interrogate

Read and interrogate Section 10.8 in the textbook and answer Review Question 10.8. What is the difference between "describe" and "explain"?

OALG 10.8.4 Practice

Solve Problem 56 on page 312.