Chapter 2

Kinematics: Motion in One Dimension

2.1 What is motion?

2.1.1 Describe

Class: *Equipment per group****:*** none.

Each member of your group plays a role in the story described below. Assign roles and discuss the answers to the questions. Then get up and enact the story for the rest of the class.

Story: A person sits in the passenger seat of a car that is traveling along a street. Describe the person's motion as seen by each of the following observers:

a. another person sitting in the backseat of the car;

b. a pedestrian standing on the sidewalk as the car passes; and

c. the driver of a second car moving in the same direction and passing the first car.

2.1.2 Describe

Class: *Equipment per group****:*** none.

Each member of your group plays a role in the story. Assign roles and discuss the answers to the questions. Then get up and enact the story for the rest of the class.

Story: A person stands near a bus stop. Describe the standing person's motion as seen by the following observers:

a. a person sitting in an approaching bus;

b. a person riding in a car moving away from the bus stop; and

c. another person standing at the bus stop.

2.1.3 Explain

Class: *Equipment per group**:*** none.

Discuss with your group members your analyses for Activities 2.1.1 and 2.1.2 and answer the questions that follow. Did you agree on your answers? If not, what were the contentious points?

a. Do any observers say that the person sitting in the passenger seat of the car in Activity 2.1.1 was moving? Explain.

b. Do any observers say that the person sitting in the passenger seat of the car in Activity 2.1.1 was not moving? Explain.

c. Do any observers say that the person standing near a bus stop in Activity 2.1.2 was moving?

d. Do any observers say that the person standing near a bus stop in Activity 2.1.2 was not moving?

e. Based on your answers in parts a. through d., explain what it means when someone says an object is "moving." List all explanations on the board and discuss which is the most comprehensive.

2.1.4 Describe

Class: *Equipment per group**:*** none.

Work with your group members to devise several situations in which

a. you *can* model Earth as a point-like object, and

b. you *cannot* model Earth as a point-like object.

What are the features that the part a. situations have in common and the part b. situations have in common? Can you come to a consensus in your group?

2.1.5 Reading exercise

Read Section 2.1 in the textbook and answer Review Question 2.1.

2.2 A conceptual description of motion

2.2.1 Observe

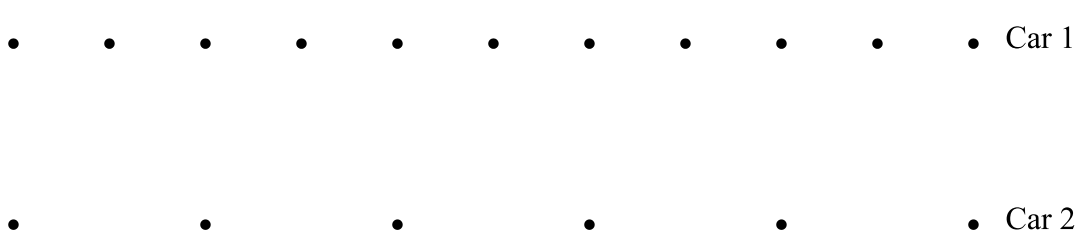
PIVOTAL ***Lab or class:*** *Equipment per group:* metronome (download a metronome app.) or any device to keep track of time in seconds, low-speed battery-operated car, sugar packets (or any other marking device), meter stick (or any other length-measuring device), whiteboard and markers.

This activity requires collaboration and coordination of all group members. Set a metronome to about one beat per second. Person 1 turns on a battery-operated toy car and releases it to roll across the floor. Person 2 places sugar packets on the floor at the points where the car is located at every blip of the metronome (instead of sugar packets you can use anything else that will allow you to mark the floor where the car was every second, be creative!). Do not try to put the sugar packets where the car was just released. After about 5 to 7 blips, stop the car and draw a sketch showing the locations of the sugar packets as dots. Discuss with the group members how you can use the dots to describe the motion of the car. After you come to a consensus, draw your representations on the board and share it with the class. [If you do not have a toy car, you can use a hard ball such as a billiard ball or bowling ball that you roll on a smooth floor.]

2.2.2 Represent and reason

Class: *Equipment per group:* none.

You have two battery-operated toy cars that you can release simultaneously on a smooth floor and a metronome set to 1-second intervals. You and a friend each walk next to one of the cars, and at every blip of the metronome, you place a sugar packet at your car's location. The dots in the figure below represent the locations of the packets for the two cars. The cars start simultaneously at the dot on the left and move to the right.



Discuss with your group members how to answer the questions below. Make sure that you can defend your point of view using the evidence presented in the diagrams.

a. Were the cars ever next to each other? If so, where?

b. If there were a passenger in car 1, how would the passenger describe the motion of car 2?

c. If there were a passenger in car 2, how would the passenger describe the motion of car 1?

2.2.3 Observe

***PIVOTAL* Lab or class:** *Equipment per group:* metronome or any device to keep track of time in seconds, any light/soft rubber ball or under-inflated basket ball, sugar packets (or any other marking device), meter stick (or any other length-measuring device), whiteboard and markers.

This activity requires collaboration and coordination of all group members. One group member sets a metronome to 1-second intervals. Another person places a flexible ball such as a hollow rubber ball at rest on the floor (The ball should be flexible enough to change shape a little when on a surface.) This person abruptly pushes on the ball once with a ruler so that the ball rolls away from the ruler, moving with considerable speed. The third group member moves beside the ball and places sugar packets on the floor to indicate positions of the ball every second after the ruler no longer touches the ball. Discuss together: describe the motion of the ball in simple words, draw a sketch representing the sugar packets with dots, and describe the relative distance between the packets. How does the distance between the packets correspond to the observed motion of the ball?

2.2.4 Explain

Class: *Equipment per group:* none.

Examine Figure 2.2 in the textbook. Explain the changes in the light traces of the LED in each experiment. In particular:

a. What can the length of the light trace tell you about the motion of the cart?

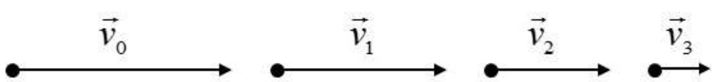
b. If each subsequent light trace gets shorter, what does that tell you about the motion of the cart?

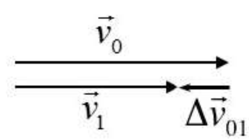
c. If each subsequent light trace gets longer, what does that tell you about the motion of the cart?

2.2.5 Represent and reason

***PIVOTAL** Class: Equipment per group:* none.

The illustration below relates to the experiment you performed with the flexible ball in Activity 2.2.3. The dots represent the locations of the ball measured each second. The arrows represent the direction of motion and how fast the ball was moving (we call them *velocity arrows*). Consider velocity arrows 0 and 1. Move them side by side with their tails at the same horizontal position. Decide what change arrow $\Delta\vec{v}_{01}$ you would have to add to arrow 0 to make it the same length as arrow 1. Repeat for arrow 1—what change arrow is needed to change it into arrow 2, and what change arrow is needed to change arrow 2 into arrow 3? We call these *velocity change arrows*.



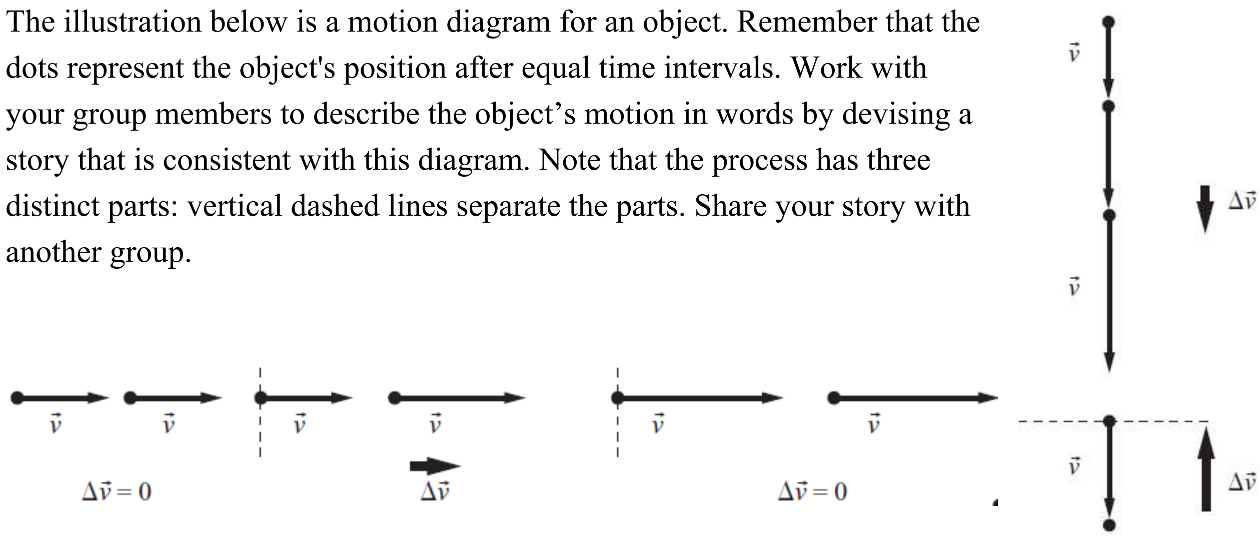


Use the Physics Tool Box 2.1 to learn how to represent motion using qualitative motion diagrams.

2.2.6 Represent and reason

***PIVOTAL** Class: Equipment per group:* none.

The illustration below is a motion diagram for an object. Remember that the dots represent the object's position after equal time intervals. Work with your group members to describe the object's motion in words by devising a story that is consistent with this diagram. Note that the process has three distinct parts: vertical dashed lines separate the parts. Share your story with another group.



2.2.7 Represent and reason

Class: *Equipment per group:* none.

The illustration to the right is a motion diagram for an object. Work with your group members to describe the object's motion in words by devising a story that is consistent with this diagram. Note that the process has two distinct parts: the horizontal dashed line separates the parts. Share your story with another group.

2.2.8 Represent and reason

Class: *Equipment per group:* whiteboard and markers.

A car stops for a red light. When the light turns green, the car moves forward for 3 s at a steadily increasing speed. The car then travels at constant speed for another 3 s. Finally, when approaching another red light, the car steadily slows to a stop during the next 3 s. Using the whiteboard and markers, work with your group members to draw a motion diagram that describes this process. What difficulties did you encounter? What parts of the activity led to discussions? Share your diagram with another group.

2.2.9 Reading exercise

Read Section 2.2 in the textbook and answer Review Question 2.2.

2.3 Operations with vectors

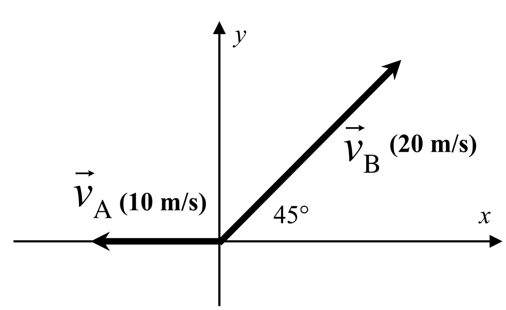
2.3.1 Read and analyze

Work through Section 2.3 in the textbook and discuss with your group members what a vector is and how operations with vectors are different from operations with numbers.

2.3.2 Practice

Class: *Equipment per group:* whiteboard and markers, meter stick, protractor.

Do this together with your group on a whiteboard. For the velocity vectors $\vec{v}_A$ and $\vec{v}_B$ shown in the figure to the right, use a meter stick and markers to draw the



vectors head-to-tail to find the magnitude and direction of

a. the sum of the two vectors $\vec{v}_A + \vec{v}_B$, and

b. the difference of the two vectors: $\vec{v}_A - \vec{v}_B$.

Next, use your answers from parts a. and b. to find the magnitude and direction of

c. $-\vec{v}_A - \vec{v}_B$, and

d. $\vec{v}_B - \vec{v}_A$.

(Note: to get accurate results, you need to draw your vectors to scale.)

2.3.3 Practice

PIVOTAL* *Class: *Equipment per group:* whiteboard and markers, meter stick, protractor.

On your group's whiteboard (or in your notebook) draw arbitrary vectors $\vec{A}$, $\vec{B}$, $\vec{C}$, $\vec{D}$, and $\vec{E}$ that have different magnitudes and directions.

a. Brainstorm with your group about what operations with vectors you know. Consult textbook Section 2.3. Make a list.

b. For each operation, draw at least two examples on the board using your vectors A to E. Do all group members agree with the examples?

c. Invite another group to evaluate your examples while you are evaluating theirs.

d. Based on your evaluations, decide if you need to revise the examples.

2.3.4 Evaluate

Class: *Equipment per group:* none.

Discuss with your group how finding the direction and magnitude of the $\Delta\vec{v}$ arrow on the motion diagram relates to an operation with vectors. Can you use vector addition to find $\Delta\vec{v}$? Can you use vector subtraction?

2.3.5 Reading exercise

Read Section 2.3 in the textbook and answer Review Question 2.3.

2.4 Quantities for describing motion

2.4.1 Explain

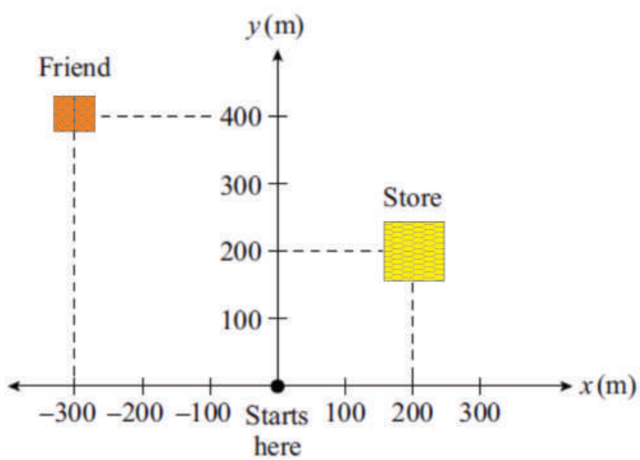
Class: *Equipment per group:* none.

Work with Chapter 1 in the textbook to learn what a physical quantity is. Discuss with your group: What is the difference between a physical quantity and unit? Give examples of physical quantities that have different units in the SI system and the British system. What are the quantities that have the same units in both systems?

2.4.2 Represent and reason

PIVOTAL ***Class:*** *Equipment per group:* whiteboard and markers, meter stick.

Henry is traveling to a store and then to his friend's house. His trip is represented on a sketch below (with a bird's eye view).



a. What is Henry's initial position? Final position? What is the position of the store?

b. Draw a vector to represent his total displacement, determine the scalar x-component of the displacement, the total distance traveled, and the path length.

c. Choose a different origin for the coordinate system and repeat parts a. and b. What quantities changed? What quantities remained the same?

2.4.3 Reason and represent

Class: *Equipment per group:* whiteboard and markers, meter stick.

Work together with your group on a whiteboard to tell a story and draw pictures representing Heather's trips A and B, as described below. On the pictures, show the coordinate axis and the displacement vector. Think of where you will choose the origin. d_x is the x-component of the displacement and l is the path length.

a. Trip A: $d_x = 0.7\,\text{mi};\ l = 2.4\,\text{mi}.$

b. Trip B: $d_x = -3.7\,\text{mi};\ l = 4.4\,\text{mi}.$

c. What are Heather's initial and final positions for each trip? How do they depend on the choice of the direction of the coordinate axis and the location of the origin?

d. Who is the observer for the trips described above? Find an observer (per trip) for whom during the same trips Heather's displacements and path lengths traveled are all zero.

2.4.4 Pose your own problem

Class: *Equipment per group:* none.

Imagine any motion you participate in every day, such as going to classes or to a movie and dinner afterward. Pose a problem to solve about this motion in which one needs to understand the difference between the physical quantities position, displacement, distance, and path length, and the difference between a vector and the scalar component of a vector.

2.4.5 Reason

Class: *Equipment per group:* none.

Discuss with your group: In each of the following measurements, how many significant figures does the measurement have and what is the absolute uncertainty in each measurement?

a. Ulani says that she used a meter stick and measured her pencil to be 0.153 m long.

b. Hermes says that the college swimming pool is 50 m long.

c. Ulani used a chemical balance to weigh her pencil and says that her pencil weighs 0.00478 kg.

d. Hermes says that he estimates that there are about 2 million liters of water in the college swimming pool.

2.4.6 Explain

PIVOTAL Class: *Equipment per group:* none.

Discuss with your group. Suppose your friend tells you that she measured her bed to be 2 m long, then she tells you that she looked up on Wikipedia that the circumference of Earth is 40,075,017 m. How many significant figures does each of these measurements have? Which of these two measurements is more precise? Discuss why. Evaluate both values and their number of significant figures.

2.4.7 Reading exercise

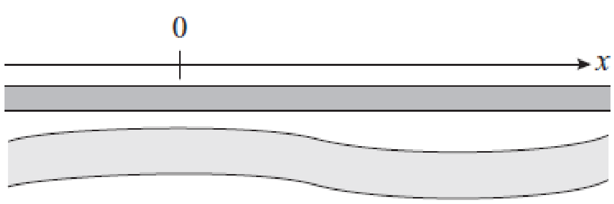
Read Section 2.4 in the textbook and answer Review Question 2.4.

2.5 Representing motion with data tables and graphs

2.5.1 Observe and describe

PIVOTAL Class: *Equipment per group:* whiteboard and markers, meter stick.

Imagine that you and your friend ride bicycles along a straight path beside a river. A coordinate axis is shown alongside the path.



The table indicates your position along the path at different clock readings.

Clock reading t (s)	Your position x (m)	Your friend's position
$t_0 = 0$	$x_0 = 640$	$x_0 = 640$
$t_1 = 20$	$x_1 = 500$	$x_1 = 490$
$t_2 = 40$	$x_2 = 360$	$x_2 = 340$
$t_3 = 60$	$x_3 = 220$	$x_3 = 190$
$t_4 = 80$	$x_4 = 80$	$x_4 = 40$
$t_5 = 100$	$x_5 = -60$	$x_5 = -110$
$t_6 = 120$	$x_6 = -200$	$x_6 = -260$

a. Work with your group members to write everything you can about the bike rides and indicate any pattern in the data. What was happening at the clock reading of zero?

b. Draw motion diagrams for both bikes.

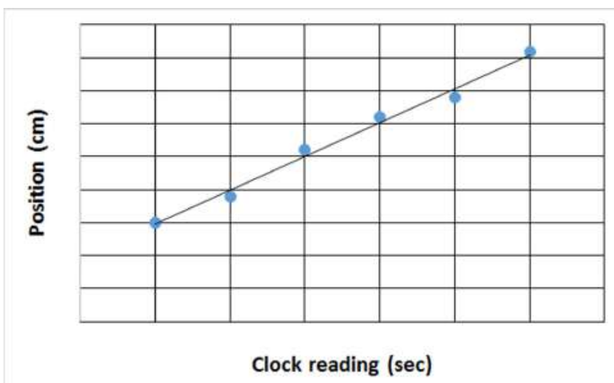
c. Construct position-versus-clock-reading graphs for both bike trips using the same coordinate axes in which *x* is a dependent variable and *t* is an independent variable. Compare and contrast the graphs – how do the graph lines represent the differences in the bikes' motions? Check with other groups – are their graphs the same or different from the graph of your group?

d. Discuss with your group members how the motion diagrams in part b. correspond to the graphs. How do you need to position the motion diagrams with respect to the graph axes so that it helps you visualize the motions?

2.5.2 Represent and reason

Class: *Equipment per group:* whiteboard and markers, meter stick.

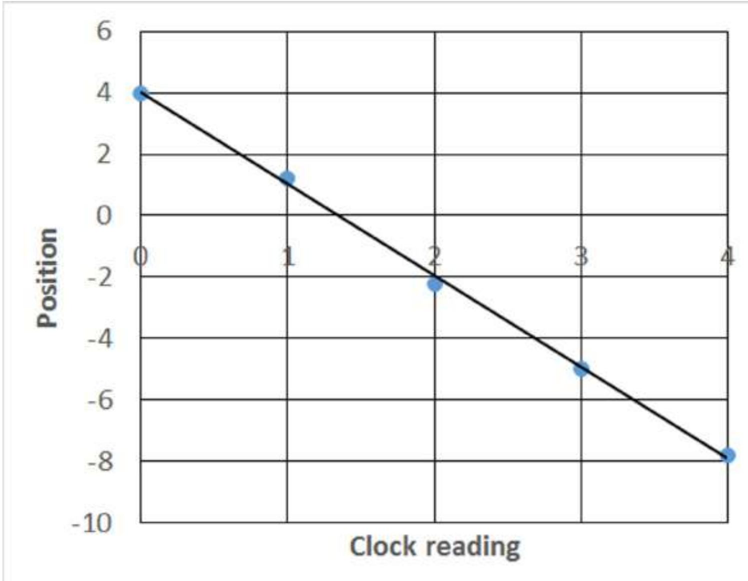
With your group members, examine the graph below. On a whiteboard, describe the motion in words, construct a motion diagram for the motion, and a table of data.



2.5.3 Represent and reason

Class: *Equipment per group:* whiteboard and markers, meter stick.

Examine the graph below. Is the graph complete? If not, complete it and represent the same information with a table and the motion diagram.



2.5.4 Reading exercise

Read Section 2.5 in the textbook and answer Review Question 2.5.

2.6 Constant velocity linear motion

2.6.1 Represent mathematically

PIVOTAL Class: *Equipment per group:* whiteboard and markers.

Work together with your group members to answer the following questions:

a. Examine the graphs you drew in Activity 2.5.1c. Write two function expressions $x(t)$ for the graphs. Consider your labeling system: how can you distinguish the function for your bike from the function for your friend's bike?

b. What are the physical meanings of the slope of each function and the intercepts? What common name can you use for the slope? Explain the meanings of positive or negative values for these quantities.

c. Compare and contrast how we write linear functions in mathematics to how you just wrote the position-versus-time functions for motion. What is the same between them? What is different?

2.6.2 Test your idea

PIVOTAL Lab: *Equipment per group:* whiteboard and markers, metronome or any device to keep track of seconds, 2 battery-operated toy cars that move with *different* speeds, sugar packets (or any other marking device), meter stick or ideally a longer tape measure.

Work with your group members on the following assignments. Make sure that your group keeps detailed records of the experiments so that another group from your class can repeat the experiments and get the same results.

a. For car A, design an experiment to decide if the car moves with constant velocity. If it does, determine the magnitude of the velocity (the car's speed).

b. For car B, use the same equipment and method to decide if this car moves with constant velocity. If it does, determine the magnitude of the velocity (the car's speed).

c. Predict where the cars will meet if you simultaneously release them from 2.0 m apart moving straight toward each other. List all assumptions that you made about how the cars move. If the assumptions were not valid, how would your prediction change?

d. Decide how you will record the data. How will you represent the data? In your representation, mark the predicted value for the meeting location. Perform the experiment and collect data.

e. Did the outcome match your prediction? How many times do you need to conduct the experiment to be able to say for sure whether the outcome of the experiment matches the prediction or not? Write the result of the experiment (meeting location) accounting for the discrepancies in the meeting location in different repetitions of the experiment.

2.6.3 Represent

Class: *Equipment per group:* none.

The motion of two objects is represented by the expressions below. Study the motions and act them out with your classmates. Note that it is important to focus on what was happening at $t = 0$. What are your assumptions about the observer?

$$x_{\mathrm{A}} = (-7.5\ \mathrm{m}) + (1.7\ \mathrm{m/s})t$$
$$x_{\mathrm{B}} = (5.2\ \mathrm{m}) + (-0.8\ \mathrm{m/s})t$$

2.6.4 Apply

***PIVOTAL* Lab:** *Equipment per group:* whiteboard and markers, motion detector, meter stick or any other length-measuring device.

Practice using the motion detector until you are comfortable with it, and you know the range of distances it detects and what direction of motion is positive.

a. Discuss with your group members what the position-versus-time graphs of the motions described by the expressions below will look like, and sketch the graphs.

$$x = 2\text{ m} + (-1.0\text{ m/s})t$$
$$x = (1.5\text{ m/s})t$$

b. Choose one group member to perform the motions in front of the motion detector and compare the graphs on the motion detector's screen with those predicted in part a.

2.6.5 Reason

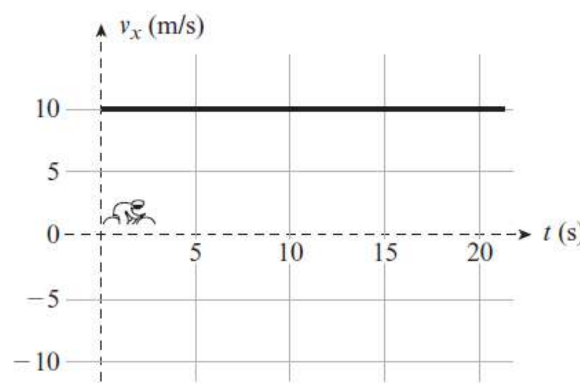
Class: *Equipment per group:* whiteboard and markers.

Work together with your group members. You are sitting on a park bench. A jogger is passing the bench, jogging at a relatively constant speed of 6 mph when you start observing her. Write a position-versus-time function for the jogger that will allow you to predict her position at any clock reading. What assumptions do you need to make to write this function? How many "correct" functions can you write?

2.6.6 Analyze

***PIVOTAL* Class:** *Equipment per group:* whiteboard and markers.

Share ideas with your group members and figure this out together. The figure at the right shows a *velocity*-versus-time graph that represents the motion of a bicycle moving along a straight bike path. The positive direction of the velocity coordinate axis is toward the east.



a. Use the graph to estimate the bike's displacement during the time interval from clock reading 10 s to clock reading 15 s.

b. Use the graph to estimate its displacement during the time interval from 0 s to 20 s.

c. Formulate a general rule for using a velocity-versus-time graph to determine an object's displacement during some time interval if the object is moving at constant velocity.

2.6.7 Test an idea

Lab: *Equipment per group:* whiteboard and markers, motion detector (if available), a small object that can be dropped and will not bounce, meter stick or any other length-measuring device, video camera. [https://mediaplayer.pearsoncmg.com/assets/_frames.true/sci-phys-egv2e-alg-2-6-7]

Use available equipment to design an experiment to test if the motion of the object that you drop from certain height can be described mathematically as $y = v_y t$. Consider the location from which the object is dropped to be the origin.

a. Discuss with your group members what it means to test an idea. In physics, experimental testing consists of the following steps:

1) you accept the idea being tested as true;

2) you design an experiment whose outcome you can predict using this idea;

3) you make the prediction of the outcome (here you also need to think of what you assume to be true in addition to the idea you are testing—these are called *assumptions*);

4) you perform the experiment and compare the outcome to the prediction, and based on the comparison you make your judgment concerning the idea being tested.

b. Design an experiment and make a prediction of the expected results based on the idea being tested. Be sure to write your prediction down.

c. Then perform the experiment as many times as necessary for you to be convinced that the data you collected are sufficient to support or reject the idea. Record the data and justify your judgment.

2.6.8 Apply

A total solar eclipse is a rare phenomenon that happens at the same location once in about 200 years. During this phenomenon, the Moon passes directly in front of the Sun as seen from Earth. Given the visible diameter of the Moon is very close to the visible diameter of the Sun, the Moon covers the Sun completely and the part of Earth in the Moon's shadow plunges into darkness during the daytime. The average shadow of the Moon on Earth is about 200 km wide and it

slowly travels across Earth during the eclipse day. On August 21st 2017, this rare phenomenon occurred in the US. Below are the data about the eclipse. Work with your group members to answer the questions below. (The photo above shows the Sun in Franklin, NC, about 5 minutes before the total solar eclipse in 2017).

a. The 2017 total solar eclipse started on Monday August 21 in Madras, Oregon at about 10:20 am (Pacific daylight time) and ended in Columbia, South Carolina at 2:44 pm (Eastern daylight time). Estimate the average speed of the Moon's shadow moving across the United States and compare it to the speed of sound in air (340 m/s). Indicate any assumptions that you made.

b. During the same total solar eclipse in Franklin, North Carolina, the Moon cast on Earth a circular shadow with a diameter of about 109 km. The total solar eclipse in Franklin lasted for 2 minutes and 30 seconds. Estimate the speed of the Moon's shadow moving across Franklin. Compare this answer with the answer in part a. and try to explain any discrepancies.

2.6.9 Reading exercise

Read Section 2.6 in the textbook and answer Review Question 2.6.

2.7 Motion at constant acceleration

2.7.1 Observe and analyze

PIVOTAL ***Lab or class:*** *Equipment per group:* whiteboard and markers, motion detector (if available), a small object that can be dropped and will not bounce, meter stick or any other length-measuring device, video camera.[https://mediaplayer.pearsoncmg.com/assets/_frames.true/sci-phys-egv2e-alg-2-7-1]

a. Use the available equipment to design an experiment to record position-versus-time data for a ball falling from the height of about 2 meters. It helps to position the motion detector above the falling ball, not below.

b. Perform the experiment and collect data. If you are using a motion detector, the data will be represented as a graph right away. If you are analyzing a video, you will need to figure out how to collect position and time data from it. Repeat the experiment a few times. What can you say about the motion of the ball based on the data you collected?

c. Draw a motion diagram for the ball.

d. Draw a position-versus-time graph for the ball. Discuss whether the graph resembles a position-versus-time graph for an object moving at constant velocity.

e. Determine the scalar component of the average velocity for the ball for each time interval by completing the following table.

Time interval $\Delta t = t_n - t_{n-1}$	Displacement $\Delta x = x_n - x_{n-1}$	Average time $(t_n + t_{n-1})/2$	Average velocity $\frac{\Delta x}{\Delta t}$

f. Plot this average velocity v_x on a velocity-versus-time graph. The time coordinate for each average velocity coordinate should be in the middle of the corresponding time interval (the average time for that time interval). Draw a best-fit line for your graph.

g. Discuss with your group the shape of the graph: How does the speed change as time elapses? Suggest a name for the slope of the graph.

2.7.2 Analyze

Class: *Equipment per group:* whiteboard and markers.

If you did not perform the experiment in Activity 2.7.1, work with the data recorded in the table at the right for the up and down motion of the center of a ball thrown upward (the y-axis points up).

Clock reading *t* (s)	**Position *y* (m)**
0.000	0.00
0.133	0.44
0.267	0.71
0.400	0.80
0.533	0.71
0.667	0.42
0.800	- 0.04

a. Sketch a motion diagram for the ball modeled as a point-like object.

b. Draw a position-versus-time graph.

c. Draw a velocity-versus-time graph. Find its slope. What do you call this slope?

d. Use the velocity-versus-time graph to determine the ball's acceleration at the very top of its trajectory.

e. What is the ball's velocity at the top?

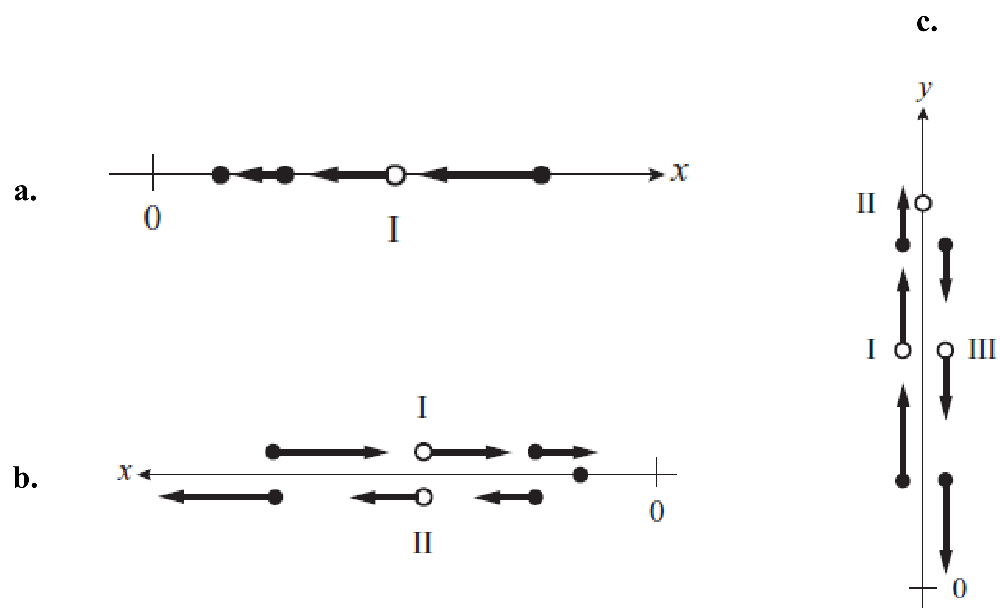
f. Can you reconcile these two answers? Explain.

g. Use the velocity-versus-time graph to determine the distance that the ball traveled during the trip from clock reading 0.000 s to 0.800 s.

2.7.3 Represent and reason

Class: *Equipment per group:* whiteboard and markers.

The motion diagrams in the illustrations below represent the motion of different objects. The arrows are velocity arrows.



A different coordinate axis is provided for each of the three motion diagrams. An open circle indicates a location of interest (there are three locations: I, II, and III). Add a single velocity change arrow for each diagram. Then, determine the signs of the position, velocity component, velocity change component, and acceleration component at the position(s) of the open dots for each diagram. Note: what assumptions about motion do you need to make to use only *one* velocity change arrow for part b. and one for part c.

2.7.4 Reading exercise

Read Section 2.7 in the textbook and answer Review Question 2.7.

2.8 Displacement of an object moving at constant acceleration

2.8.1 Derive

***PIVOTAL* Class:** *Equipment per group:* whiteboard and markers.

Discuss with your group members how you can construct a function $x(t)$ for a cart that moves at constant acceleration. Choose the simple case first: when the cart starts at the origin of the coordinate system and has zero initial speed. There are many ways of doing this. Think of average velocity or a velocity-versus-time graph. Once you agree on the method, follow through and derive the expression. Evaluate the expression using limiting case analysis – for example, does your equation work for constant-velocity motion? Share the expression with the class – are you in agreement concerning the function $x(t)$?

2.8.2 Design an experiment

Lab: *Equipment per group:* Low-friction track and a cart, motion detector or a stopwatch, meter stick.

Design an experiment to investigate the motion of a cart moving up and down an inclined plane. You push it forcefully at the bottom of the plane so that it moves up the slope, and then it stops and moves back down. You can use a motion detector, a stopwatch, a meter stick, and other equipment available in the lab.

a. Describe your experiment in words and draw the setup.

b. What data will you collect?

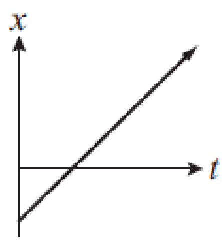
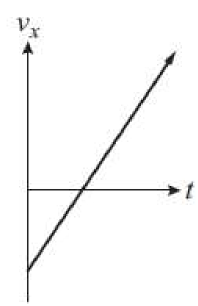
c. How will you organize and report your data so that others can understand it?

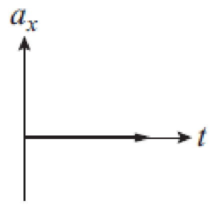
d. After you have made all the decisions, conduct the experiment and write down your findings. What can you say about the motion of the cart?

2.8.3 Summarize

***PIVOTAL* Class:** *Equipment per group:* whiteboard and markers.

This is a really helpful activity to do with your group: Use different representations of the two types of motion we have studied to fill in the empty cells in the table. Some cells are completed to give you an idea of the motions and the direction of the coordinate axis for each case. Your responses should relate to the motion already described. Completing the table will help you summarize everything you have learned about the description of motion. Resolve any confusion you may have by talking with your group members.

Motion with constant velocity	**Motion with constant acceleration**
Describe the motion in words, providing an example.	Describe the motion in words, providing an example. The object's velocity is decreasing by the same amount every second—for example, a cart going up a smooth track tilted at an angle.
Provide a motion diagram that describes this type of motion.	Provide a motion diagram that describes this type of motion.
Provide a position-versus-time graph that describes this type of motion. 	Provide a position-versus-time graph that describes this type of motion.
Describe the motion mathematically as $x(t)$.	Describe the motion mathematically as $x(t)$. $x = -v_0 t + \frac{1}{2} a_{x0} t^2$
Provide a velocity-versus-time graph that describes this type of motion.	Provide a velocity-versus-time graph that describes this type of motion. 
Describe the motion mathematically as $v_x(t)$. $v_x = v_{x0}$	Describe the motion mathematically as $v_x(t)$.
Provide an acceleration-versus-time graph	Provide an acceleration-versus-time graph that

that describes this type of motion. 	describes this type of motion.
Describe motion mathematically as $a_x(t)$.	Describe motion mathematically as $a_x(t)$. $a_x = a_{x0}$

2.8.4 Reading exercise

Read Section 2.8 in the textbook and answer Review Question 2.8.

2.9 Skills for analyzing situations involving motion

2.9.1. Represent and reason

Class: *Equipment per group:* whiteboard and markers.

You have two identical billiard balls at the top of an inclined track. Assume that the balls move along the incline in the same way a small cart does (i.e., with constant acceleration). Now imagine you release one ball and it moves down the track. When it is about 10 cm down the track, you release the second ball. Draw a picture of the situation and describe it using motion diagrams, graphs, and mathematical equations. Use those representations to predict what will happen to the distance between the two balls – will it increase, decrease, or stay the same (about 10 cm)?

2.9.2 Represent and reason

PIVOTAL Class: *Equipment per group:* whiteboard and markers.

Practice representing a process involving motion on a whiteboard together with your group members. A stoplight turns yellow when you are 20 m from the edge of an intersection. Your car is traveling at 12 m/s. After you hit the brakes, your car's speed decreases at a rate of 6.0 m/s each second until the car stops. Ignore the reaction time needed to move your foot from the floor to the brake pedal.

a. Sketch the process. Indicate the origin of the coordinate system and the direction of the *x*-axis.

b. Draw a motion diagram representing the process. What are the signs of the v_x, Δv_x and a_x?

c. Construct an $x(t)$ graph for the process.

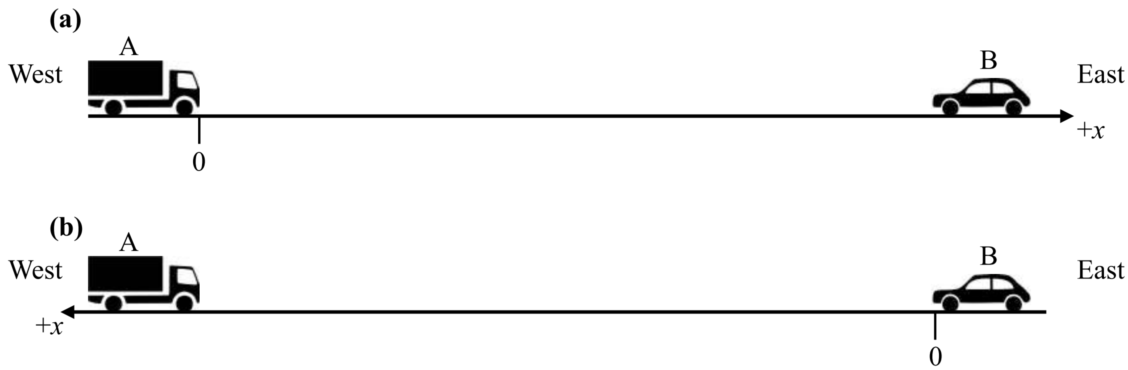
d. Construct a $v_x(t)$ graph for the process.

e. Write $x(t)$ and $v_x(t)$ expressions representing the process.

2.9.3 Represent and reason

***PIVOTAL Class:** Equipment per group:* whiteboard and markers.

Truck A starts at rest and moves faster and faster toward the east so that its speed increases by 3.0 m/s each second. At the same time that truck A begins to move, car B is 200 m east of truck A. Car B is initially moving at speed 16 m/s toward the west and begins to slow down by 1.0 m/s each second.



Fill in the table that follows using a different description for each coordinate axis shown above.

	Truck A: coordinate system (a)	Car B: coordinate system (a)	Truck A: coordinate system (b)	Car B: coordinate system (b)
Indicate the initial clock reading.				
Indicate the initial position.				

Indicate the initial velocity.				
Indicate the acceleration.				
Write equations that can be used to determine the position and velocity of the vehicle at any given clock reading in the future (before the car stops).				

2.9.4 Regular problem

PIVOTAL Class: *Equipment per group:* whiteboard and markers.

Work together with your group to figure this out: You ride your bike west at speed 8.0 m/s. Your friend, 400 m east of you, is riding her bike west at speed 12 m/s. Complete the following steps to determine when your friend passes you.

a. *Sketch and Translate* Draw a sketch of the initial situation and choose a coordinate system to describe the motion of both bikes. Put all given information on the sketch; identify the unknown.

b. *Simplify and Diagram* Draw a motion diagram for each bike. Sketch a position-versus-time graph for each bike using the same coordinate axes.

c. *Represent Mathematically* Construct equations that describe the positions of each bicycle as a function of time relative to the chosen coordinate system.

d. *Solve and Evaluate* Use the equations to determine when the bicycles are at the same position. Does your result make intuitive sense? How do you know?

2.9.5 Represent and reason

Class: *Equipment per group:* whiteboard and markers.

An imaginary object moves horizontally. The position-versus-time function represents the object's motion mathematically. Describe in different ways a process that the equation below might represent. (The equation could represent many different processes.) Work together with your group, and when you're done or if you get stuck, compare your ideas with another group.

$$x(t) = (-200.0\text{ m}) + (-20.0\text{ m/s})t + (1.0\text{ m/s}^2)t^2$$

a. Describe the motion in words. Note that it is important to focus on what was happening at $t = 0$. Use physical quantities to write down all of the information that you can "extract" from the function. If you can write other functional dependencies – do it!

b. Draw a motion diagram that represents the process.

c. Draw a position-versus-time graph that represents the process.

d. Draw a velocity-versus-time graph that represents the process.

e. Determine when and where the object for your chosen process stops.

f. If you decided to let the process continue beyond the point where it stops in e. above, what would the object be doing?

2.9.6 Evaluate

Class: *Equipment per group:* whiteboard and markers.

Discuss with your group: You learned that the equation describing position-versus-time of an object moving at constant acceleration is $x = x_0 + v_{x0}t + \frac{1}{2}a_x t^2$. Use both algebraic and graphical approaches to show that, in a limiting case of $a_x = 0$, this equation describes the motion of an object that is traveling at constant velocity.

2.9.7 Evaluate

Class: *Equipment per group:* whiteboard and markers.

Discuss with your group: You learned that in the equation describing an object moving at constant acceleration, the position as a function of time is $x = x_0 + v_{x0}t + \frac{1}{2}a_x t^2$. Use algebraic and graphical approaches to show that, in the case where $x_0 = 0$ and $v_{x0} = 0$, the successive displacements of the object change in proportion as the integers squared: 1, 4, 9, 25, etc.

2.9.8 Evaluate the solution

Class: *Equipment per group:* whiteboard and markers.

Discuss with your group: Identify any errors in the proposed solution to the following problem and provide a corrected solution if there are errors.

The problem You are driving at 20 m/s and slam on the brakes to avoid a goose walking across the road. You stop in 1.2 s. How far did you travel after hitting the brakes?

Proposed solution

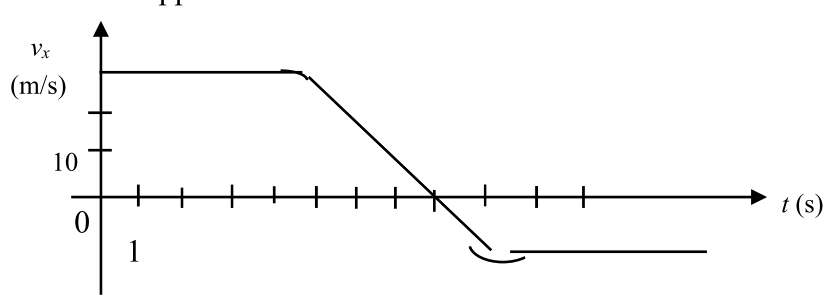
$$(x - x_0) = vt = (20\text{ m/s})(1.2\text{ s}) = 24\text{ m}$$

2.9.9 Evaluate the solution

Class: *Equipment per group:* whiteboard and markers.

Discuss with your group: Identify any errors in the proposed solution to the following problem and provide a corrected solution if there are errors.

Problem: Use the following graphical representation of motion to determine how far the object traveled before it stopped.



Proposed solution The object was at rest for about 5 seconds, then started moving in the negative direction and stopped after about 9 seconds. During this time, its position changed from 30 m to – 10 m, so the total distance that it traveled was 40 m.

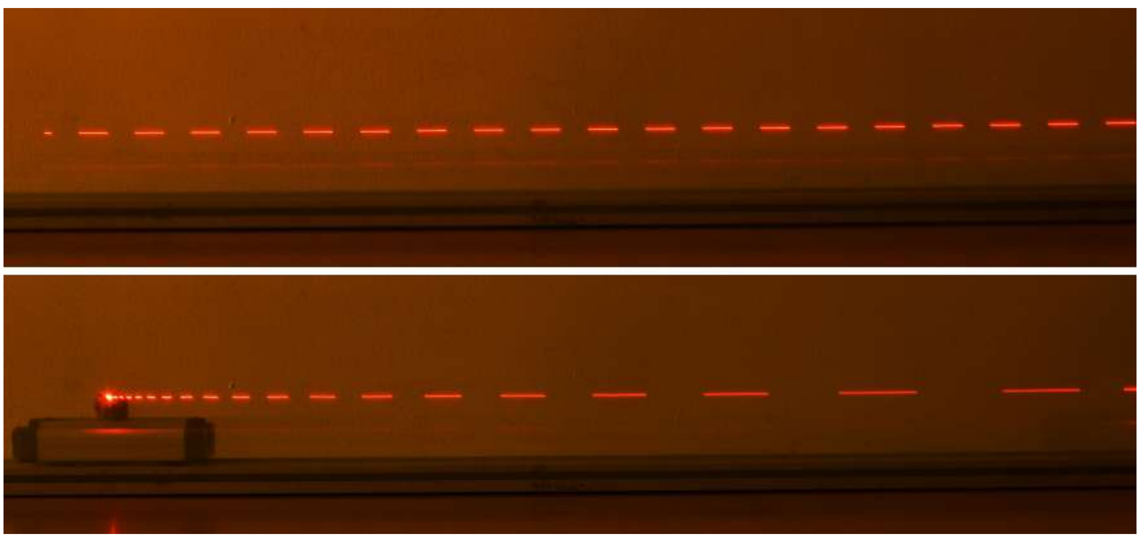
2.9.10 Observe and analyze

Class: *Equipment per group:* whiteboard and markers.

Collaborate together with your group to figure this out: The figure below shows long-exposure photos of two experiments with a blinking LED that was fixed on a moving cart. In both cases the cart was moving from right to left. The duration of the ON and OFF times for the LED is 154 ms, and the length of the cart is 17 cm.

a. Specify a coordinate system and draw a qualitative velocity-versus-time graph for the motion of the cart in both experiments.

b. Estimate the speed of the cart in the first experiment. Both photos were taken from the same spot and with the same settings. Indicate any assumptions that you made.



2.9.11 Observe and analyze

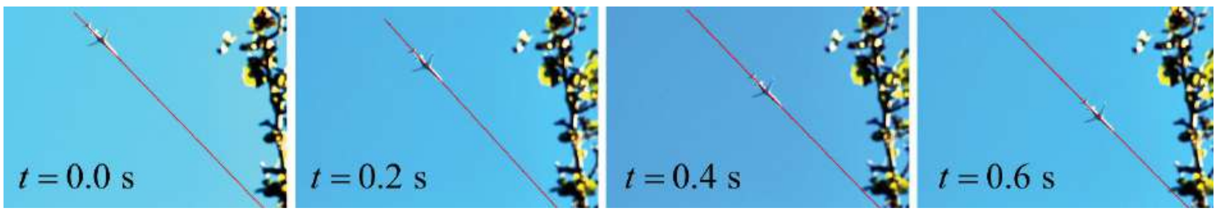
Class: *Equipment per group:* whiteboard and markers.

Collaborate together with your group to figure this out: Daniel fixed a camera on a tripod and took four successive photos of an airplane that was flying above him. The time interval between the photos was 0.2 s (see the first figure below; a straight line was added later to help you compare the position of the airplane in the different photos).

a. Draw a motion diagram for the airplane.

b. Estimate the length of the airplane using the magnified photo (shown in the second figure below) of the airplane and data that you can find on the Internet. Indicate any assumptions that you made.

c. Draw labeled position-versus-time and velocity-versus-time graphs for the airplane's motion. Indicate your assumptions (they will relate to the airplane you choose and the direction of motion) and the choice of a coordinate system. Make sure the axes of your graphs contain units. Note that you will need a ruler to solve this problem.



2.9.12A Linearize

Class: *Equipment per group:* none.

You are testing your new motion detector at an open window when suddenly a stuffed Piglet passes by. While Piglet is moving downward, you manage to record the data shown in the table at right about its motion with your motion detector.

t **(s)**	***v*** **(m/s)**
0.00	10.9
0.05	11.3
0.10	11.7
0.15	12.0
0.20	12.4
0.25	12.8

Estimate how far above your window lives the child who dropped Piglet. What else can you estimate from these data? Indicate any assumptions that you made (Note: the acceleration of falling Piglet may be significantly less than g).

2.9.12B Design an experiment

Lab: *Equipment per group:* a cotton ball, a stopwatch, and a meter stick.

Work together with your group.

a. Describe in detail (including a sketch) an experiment that you can perform to determine whether a cotton ball falls with constant speed, constant acceleration, or changing acceleration.

b. Write the physical quantities that you will measure and the quantities that you will calculate.

c. List experimental uncertainties and how you will minimize them.

d. Perform the experiment; record the data in a table, and use a best-fit curve for the data to make a judgment.

e. Write your analysis and conclusion about the cotton ball's motion.

2.9.13 Reading exercise

Read Section 2.9 in the textbook and answer Review Question 2.9.

2.9.14 Observe and analyze

Class: *Equipment per group:* whiteboard and markers.
[https://mediaplayer.pearsoncmg.com/assets/_frames.true/sci-phys-egv2e-alg-2-9-14]

Together with your group, watch the video at link above. Take relevant data from the video, draw motion diagram(s), and plot appropriate graphs to fully analyze the motion of the cotton ball. Write up a short report of your results and analysis. In conclusion, what can you say about the motion of the cotton ball from your analysis?

2.9.15 Evaluate the solution

Lab: *Equipment per group:* whiteboard and markers, stopwatch, cotton ball, meter stick.

Allison proposes the following experiment to investigate the motion of cotton balls: Drop one ball from 1 m above a surface and record the time during which it falls. If it falls at constant speed, then when it is dropped from a height of 2 m, the time of fall should double. If it falls at constant acceleration, the time should be equal to the square root of twice the time it took the ball to fall from 1 m. Now that the predictions for the two models are made, perform the experiment with the aid of your group members, dropping the ball from first 1 m and then 2 m and record the times of fall. Depending on the outcome, discard one or both models of the motion. What do you think of Allison's design, her description of the experiment, and her mathematical analysis? Compare your ideas with another group.