Chapter 4

Applying Newton's Laws

4.1 Vectors in two dimensions and force components

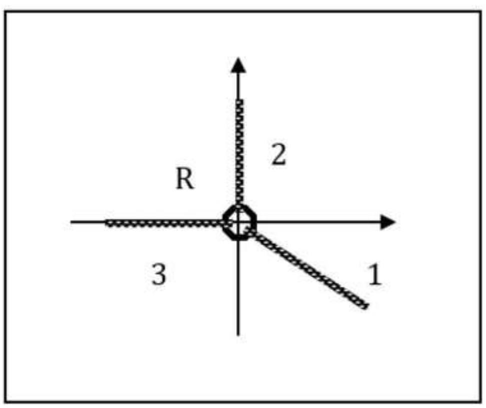
4.1.1 Components of force vectors

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

The sketch below shows three strings pulling in different directions in a horizontal plane on a small ring (R) at the center. A force diagram for the ring is also shown on a grid.

a. Based on what you see in the force diagram, explain why the ring does not accelerate in the positive or negative *x*-direction. Be explicit.

b. Repeat for the *y*-direction.

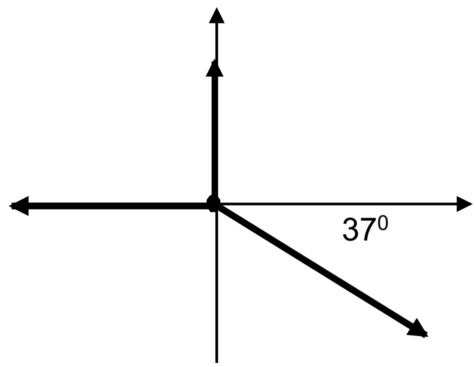


Comment Notice that string 1 exerts a 4-N force toward the right, which balances the 4-N force exerted by string 3 toward the left. Similarly, string 2 exerts a 3-N force upward, which is balanced by the 3-N downward pull exerted by string 1. If you don't see this, go back to the force diagram and try to visualize it. You should be able to realize that string 1 pulls in both the horizontal *x*-direction and the vertical *y*-direction. We say that $\vec{F}_{1\text{ on R}}$ has an *x*-component $F_{1\text{ on R}\,x} = +4\text{ N},$ and a *y*-component $F_{1\text{ on R}\,y} = -3\text{ N}.$ Normally, we don't have force diagrams on grids that allow us to visualize the components so explicitly in this way. In the next activity, we will do the same analysis using trigonometry.

4.1.2 Components of force vectors

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

The sketch on the right shows the same three strings pulling on the ring as in the previous activity. However, an angle is now shown for the pulling direction of string 1 relative to the *x*-axis.



a. How could you calculate the effect of string 1 pulling in the *x*-direction?

b. How could you calculate string 1's effect pulling in the *y*-direction? That is, how could you calculate the *x*- and *y*-components of $\vec{F}_{1 \text{ on R}}$ if you know only the magnitude of the force (5 N) and the direction of the force relative to the *x*-axis ($37°$ below the positive *x*-axis)? What are the magnitudes of the other two forces?

4.1.3 Test your ideas

Lab: *Equipment per group:* whiteboard and markers, metal ring, 3 spring scales [Alternate: Use a force table with ring, strings, pulleys, hangers and slotted objects]

Work with your group members to recreate the situation in Activity 4.1.2 and check whether the forces that you found keep the ring in the equilibrium.

4.1.4 Reading exercise Read Section 4.1 in the textbook and answer Review Question 4.1.

4.2 Newton's second law in component form

4.2.1 Real-world application: Accelerometer

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

A string with a 10-g decoration on the end is attached to the rear-view mirror of your friend's father's Ferrari. You're curious about how fast this fancy sports car can accelerate. You decide to measure the acceleration by measuring the angle that the string makes with the vertical when the car is accelerating. Your friend's father puts the pedal to the metal…Using a protractor, you measure that the angle the string makes with the vertical is 40° while the car is accelerating. What is the acceleration of the Ferrari? [Hints: Choose the decoration as the system object for your force diagram. Use the vertical-component equation of Newton's second law to find the magnitude of the force that the string exerts on the decoration. Then continue with the horizontal-component equation.]

4.2.2 Represent and reason

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

The x- and y-components of Newton's second law for a specific scenario are:

$$x:\ 1.0\ \text{m/s}^2 = (60\ \text{N}) \times (\cos 30°)/(50\ \text{kg})$$
$$y:\ 0\ \text{m/s}^2 = [(50\ \text{kg}) \times (9.8\ \text{N/kg}) + (60\ \text{N}) \times (\sin 30°) + (-520\ \text{N})]/(50\ \text{kg})$$

Discuss with your group members a force diagram for the system and a sketch of a possible scenario. How many scenarios can you come up with?

4.2.3 Reading exercise Read Section 4.2 in the textbook and answer Review Question 4.2.

4.3 Friction

4.3.1 Observe and find a pattern

PIVOTAL ***Lab or class:*** *Equipment per group:* whiteboard and markers; 5-N spring scale; a block (300-500 g) that can be pulled across the desk using the spring scale. (Alternatives: Use a wooden block with a hook screwed into the side and add 300-500 g on top of it, replace the spring scale with a force probe + computer and create a force-versus-time graph).

a. Work with your group members to perform the experiments described in the table below and to analyze them using force diagrams. Describe the patterns that you find.

Observational experiments	**Force diagram for the block** Remember that each object interacting with the block exerts one force on it
A block is at rest on the horizontal surface of a desk.	
A spring scale pulls lightly on the block that is at rest on a horizontal surface; the block does not move.	
The spring scale pulls harder on the block at rest on the horizontal surface; the block still does not move.	
The spring scale pulls even harder on the block at rest on the horizontal surface, right at the instant it starts to move.	
The spring scale pulls the block at a slow constant velocity across the horizontal surface.	
The spring scale pulls the block at a faster constant velocity across the horizontal surface.	
Patterns	

b. Discuss with your group members the direction and magnitude of the force that the desk exerts on the block in the experiments described above. Does the force have a constant magnitude? Constant direction?

c. Resolve the force that the desk exerts on the block into two components: one perpendicular to the interacting surfaces and one parallel. The perpendicular vector component is called the **normal force** (normal is the term for perpendicular in mathematics) and the parallel vector component is called the **friction force**.

4.3.2 Design an observational experiment

Lab or class: *Equipment per group:* whiteboard and markers; 5-N spring scale, a specially prepared wooden block that has the same materials on two surfaces that have different areas, and different materials on two other surfaces that have the same areas (e.g., a pair of different-area surfaces are polished wood and a matching pair have sand paper glued onto topthem); objects with different masses. (Alternative: replace the spring scale with a force probe + computer and create a force-versus-time graph).

a. Work with your group members to design an experiment to investigate what physical quantities affect the maximum static friction force component of the force that the surface exerts on the object pulled across it. Describe your experiment on the whiteboard or in your notebook with a sketch. What quantities will you vary? Remember not to vary more than one quantity at a time. Make a table to record your data.

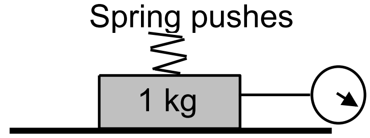
b. Conduct the experiment and record the data. What patterns did you find?

c. Talk to representatives of other groups. Did they find the same patterns?

4.3.3 Observe and find a pattern

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

Work together with your group to find a pattern from the following experimental data. A spring scale pulls a 1-kg block over a medium smooth surface. The reading of the scale can be used to determine the magnitude of the maximum static friction force—in this instance, the force when the block starts to slide. In some experiments, a compressible spring also pushes vertically down on the block (see the second block).



a. Use the data in the table to draw a graph of the maximum static friction force versus the normal force exerted by the surface on the block.

Extra downward force exerted on the 1-kg block	*N* exerted by the surface on the block, $N_{\text{s on b}}$	Maximum static friction force, $f_{\text{s on b}}$

0 N	10 N	3 N
5 N	15 N	4.5 N
10 N	20 N	6 N
20 N	30 N	9 N

b. Express mathematically a relationship between the normal force exerted by the surface and the maximum static friction force exerted by the surface. Compare your ideas with another group.

4.3.4 Observe, represent, and explain

PIVOTAL ***Lab or class:*** *Equipment per group:* whiteboard and markers; digital platform scale; an object.

Place an object on the platform scale, note the reading, then tilt the scale 10° or so. Make sure the object does not slide. Note what happens to the reading on the platform scale as you tilt it. On a whiteboard, together with your group, draw two force diagrams for the object on the scale: One for the case when the scale is level, and one for the case when the scale is tilted.

a. Discuss with your group: what happened to the magnitude of the normal component of the force exerted by the surface on the scale when you tilted it? How do you know?

b. How are the different forces (or their components) exerted on the object related to each other when the scale is tilted? Discuss what coordinate system you might want to choose to best show the key relationships. Compare your ideas with another group.

4.3.5 Reading exercise

Read Section 4.3 in the textbook and answer Review Question 4.3.

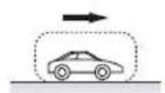
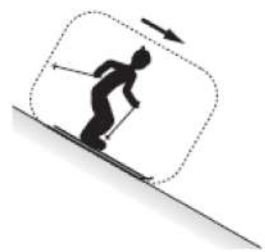
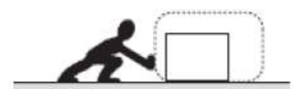
4.4 Skills for analyzing processes involving forces in two dimensions

4.4.1 Reason

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

The table below shows sketches of several situations. Divide the situations among the group members. Each member needs to draw a force diagram for the system for their respective case.

Do not forget to label each force arrow in each diagram with two subscripts—the external object causing the force, and the system. [**TIP** When choosing a coordinate system for your force diagram, start by identifying the direction that the object of interest is accelerating, or moving if there is no acceleration, and align one of your coordinate axes with that direction. If you do this, you can always draw the force vectors perpendicular to the direction of acceleration so they add to zero, because the object is not accelerating in this direction.] After each person has finished, discuss all your diagrams – what revisions do your friends suggest?

Sketch of the situation.	**a.** Person pulling a sled (smooth snow). 	**b.** Car skidding to a stop. 	**c.** Person skiing (smooth snow). 	**d.** Person pushing box. Arms point 30° below the horizontal. 
Force diagram for the system.				

4.4.2 Diagram Jeopardy

Class: *Equipment per group:* whiteboard and markers

Unlabeled force diagrams for objects moving on an inclined surface are shown below. Work individually and then discuss with your group members the following activities: For each case, sketch and describe in words a process for which the diagram might represent the forces that other objects exert on an object of interest.

Force diagram (label the force arrows).	**Sketch a situation consistent with the diagram.**	**Describe a process consistent with the diagram.**
a.		

		
b. 		

4.4.3 Evaluate the solution

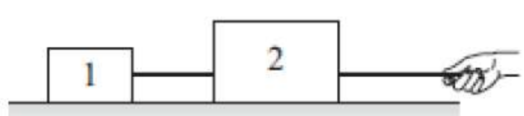
PIVOTAL Class: *Equipment per group:* whiteboard and markers.

A friend proposes that the force diagram at the right describes the forces exerted on a lawn mower during one instant while mowing the lawn; the mower is moving to the right. Discuss with your group: Could such a situation have occurred? If so, describe the situation and label the force arrows on the diagram. If not, explain why not.

4.4.4 Represent and reason

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

Two blocks on a table are connected with a light rope. Another light rope is connected to block 2 and you pull it horizontally, exerting a force $\vec{F}_{\text{Y on R2}}$. The table and the blocks are smooth.



a. Let each group member fill in the table that follows individually, then come together to answer the questions b-d below.

Experiment	**Draw a motion diagram.**	**List objects that interact with the system.**	**Draw a force diagram and find the direction of the sum of the forces.**
You pull the rope to the right exerting a force. Your system is block 2.			
You pull the rope to the right. Your system is block 1.			

b. Are your force diagrams consistent with the motion diagrams? How do you know?

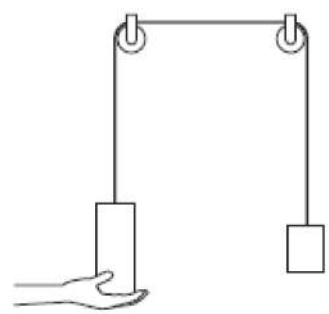
c. Are your force diagrams consistent with Newton's third law? How do you know?

d. What assumptions did you make about the force that the connecting rope exerts on each box?

4.4.5 Represent and reason

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

Two blocks are connected with a light string that runs over two light pulleys. A hand initially supports the left block, and then the hand is removed and the system is allowed to accelerate.



a. Work together with your group to fill in the table below.

Experiment	**Draw a motion diagram.**	**List objects that interact with the system.**	**Draw a force diagram and find the direction of the sum of the forces.**
The left block is at rest while held by the hand. The left block is the system.			Direction of the sum of the forces:
The right block is at rest while the hand supports the left block. The right block is the system.			Direction of the sum of the forces:
The left block (the system) after the hand is removed.			Direction of the sum of the forces:
The right block (the system) after the hand is removed.			Direction of the sum of the forces:

b. List any assumptions that you made about the magnitude of the force that the string exerts on both objects. How can you test whether those assumptions are valid?

4.4.6 Represent and reason

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

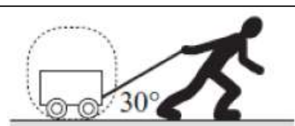
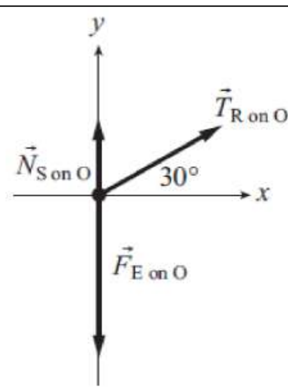
You are pulling a 20-kg sled up a smooth, $20°$ snow-covered slope. You exert a force of 170 N along the slope. What happens to the sled?

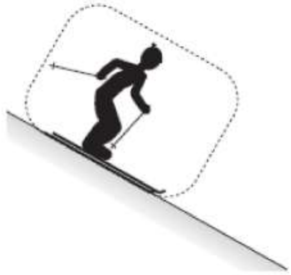
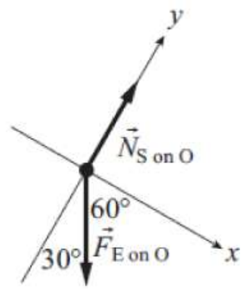
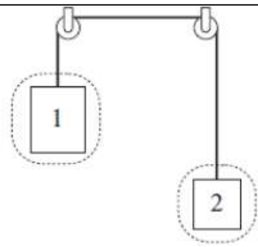
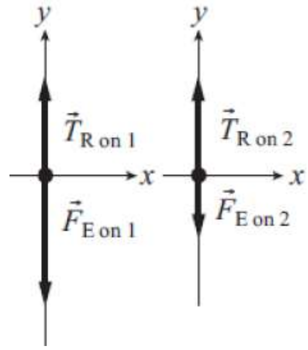
Draw a picture of the situation, label the known quantities.	**Draw a force diagram for the sled.**	**Orient the axes along and perpendicular to the slope and write Newton's second law in component form.**	**Write the expression for the acceleration of the sled. Does it make sense in the limiting case of a 0° slope? 90° slope?**

4.4.7 Represent and reason

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

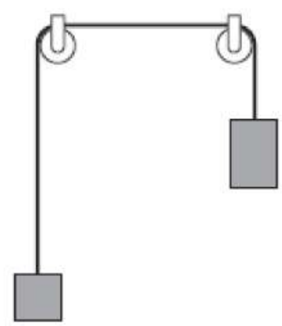
Work with your group members to complete the table that follows.

Write a word description of the situation.	**Sketch the situation and circle the system.**	**Draw a force diagram with perpendicular axes.**	**Draw a motion diagram. Are the motion diagram and force diagram consistent?**	**Write Newton's second law in compone nt form.**
				

4.4.8 Test your ideas

***PIVOTAL* Lab:** *Equipment per group:* whiteboard and markers, two-pulley (low friction) system as shown in the figure, two objects of different masses (150 g and 200 g), meter stick, stopwatch [Note: This experiment only works if the pulleys are very small and light.].

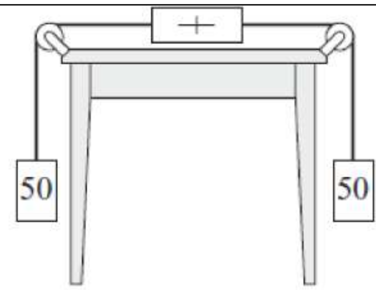
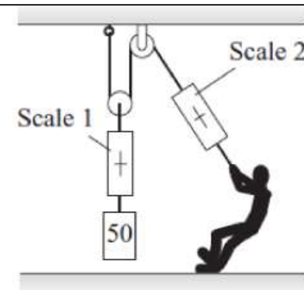


Set up an experiment as shown in the figure on the right with the object on the left having a mass of 150 g and the object on the right, 200 g. Hold the left object on a table; the right one is about 1 meter above the table. Use your knowledge of Newton's laws and kinematics to predict how long it would take the object on the right to move through a distance of 80 cm if you let go of the object on the table. After you have made your prediction, work with your group members to perform the experiment and record the time. Did the outcome match the prediction? Consider the assumptions you made about the motion of the objects, the pulleys, and uncertainties in the data.

4.4.9 Regular problem

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

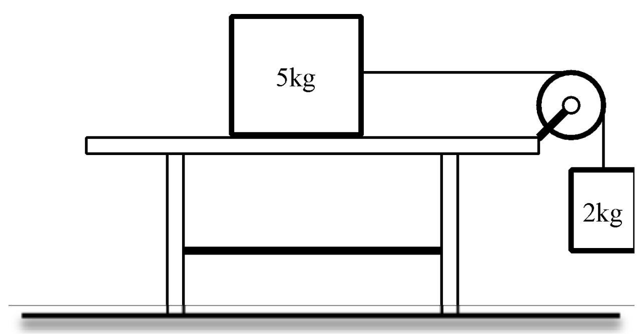
Determine the readings of all of the scales shown in the sketches in the table that follows. In each case, the scale indicates the magnitude of the force that the rope exerts on the scale. The force exerted by the rope is not changed as the massless rope passes around a pulley (the pulleys are frictionless and light; their purpose is to redirect the string). The force exerted by Earth on the blocks is 50 N. In both cases, the system is at rest (not moving).

Sketch the problem situation.		
Draw a force diagram for a chosen system/systems. Remember the perpendicular *x*- and *y*-axes.		
Apply Newton's second law in component form (*x*- and *y*-axes) to the situation shown in the force diagram.		
Solve the equations for an unknown quantity and evaluate the results to see if they are reasonable.		

4.4.10 Application

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

Find the acceleration of this system and the force exerted by the rope on either the 5 kg block or the 2 kg block. There is a coefficient of kinetic friction between the 5 kg block and the table: μ_k=0.1. Evaluate your answer. Discuss with your group what you need to assume to solve this problem.



4.4.11 Equation Jeopardy

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

Work with your group to envision one physical process that the equations below might describe (there are many possibilities). Assume that $g = 10 \text{ N/kg}$. (Note: Here N stands for the unit Newton and *N* stands for the normal force.) The object is on an incline.

$$x: \; a_x = [0 + (-(100 \text{ kg}) \times (10 \text{ N/kg}) \times \cos 20°)]/(100 \text{ kg})$$
$$y: \; 0 = [N + (-(100 \text{ kg}) \times (10 \text{ N/kg}) \times \sin 20°)]/(100 \text{ kg})$$
$$0 - (16 \text{ m/s}) = a_x t$$

On a whiteboard, construct a sketch of a process the equations might describe and write in words a problem for which the equations might be used. Compare what you came up with to the ideas of another group. Evaluate whether their picture and words are consistent with the given equations.

4.4.12 Equation Jeopardy

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

Envision one process that the equations below might describe (there are many possibilities). Assume that $g = 10 \text{ N/kg}$. (Note: Here N stands for the unit Newton and *N* stands for the normal force.) The object is on a level surface.

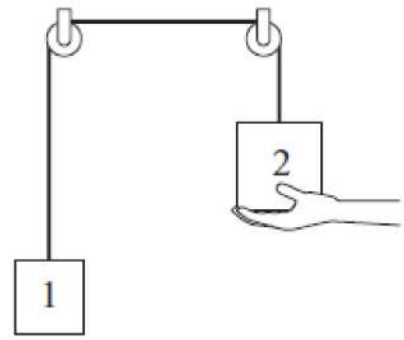
$$x: \; a_x = [(100 \text{ N}) \times (\cos 37°) + 0 + (-0.40 \text{ N}) + 0]/(10 \text{ kg})$$
$$y: \; 0 = [(100 \text{ N}) \times (\sin 37°) + N + 0 + (-(10 \text{ kg}) \times (10 \text{ N/kg}))]/(10 \text{ kg})$$
$$v_f - 0 = a_x \times (5.0 \text{ s})$$

On a whiteboard, construct a sketch of a process the equations might describe and write in words a problem for which the equations might be used. Compare what you came up with to the ideas of another group. Evaluate whether their picture and words are consistent with the given equations.

4.4.13 Pose a problem

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

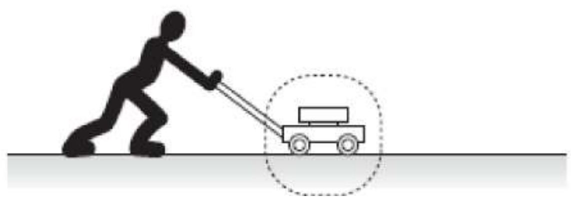
Refer to the illustration at the right to pose a problem that can be solved using Newton's second law and kinematics. Make sure you provide enough information in your problem so that it can be solved. Create your problem on a whiteboard. Then exchange your whiteboard with another group's whiteboard and see if you can solve each other's problems.



4.4.14 Evaluate the solution

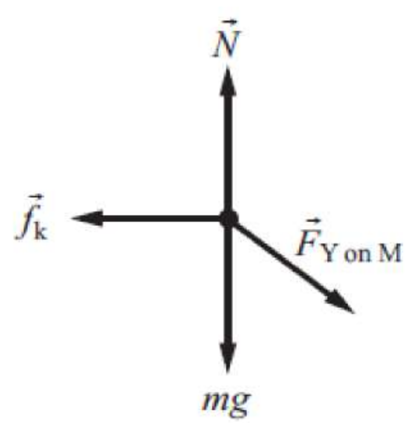
Class: *Equipment per group:* whiteboard and markers.

Work with your group to identify any errors in the solution to the following problem and provide a corrected solution if needed.



The problem: You push a 20-kg lawn mower, exerting a 100-N force on it. You push $37°$ below the horizontal. The coefficient of kinetic friction between the grass and mower is 0.60. Determine the acceleration of the lawn mower. Assume that $g = 10\ \text{m/s}^2$.

Proposed solution: The situation is pictured at the right. The mower is the object of interest and is considered a point-like object. The forces that other objects exert on the mower are shown in the force diagram. The magnitude of the kinetic friction force is:



$$f_k = \mu_k N = 0.60 \times (20\ \text{kg}) \times (10\ \text{N/kg}) = 120\ \text{N}$$

The acceleration of the mower is:

$$a_x = (F - f_\text{k}) / m = [(100\text{ N}) - (120\text{ N})] / (20\text{ kg}) = -1.0\text{ m/s}^2$$

4.4.15 Design an experiment

***PIVOTAL* Lab:** *Equipment per group:* whiteboard and markers, spring scale [alternative: force probe and computer], rigid floor tile [alternative: any rigid wooden board or plank], meter stick.

Your group is tasked by a floor tile company to determine the coefficient of static friction between your shoe and their floor tile in two different ways. You have the following equipment: a shoe, a spring scale or force probe, a floor tile, and a meter stick.

a. Devise the first method using the spring scale or force probe as your only measuring instrument. Include a sketch of your proposed method, a force diagram, and a detailed mathematical description that can be used to get a quantitative answer to the problem. Take your measurements, record your results and estimate the uncertainty in your measured value of μ_s.

b. Devise a second method using the meter stick as your only measuring instrument. Include a sketch of your proposed method, a force diagram, and a detailed mathematical description that can be used to get a quantitative answer to the problem. Take your measurements, record your results and estimate the uncertainty in your measured value of μ_s.

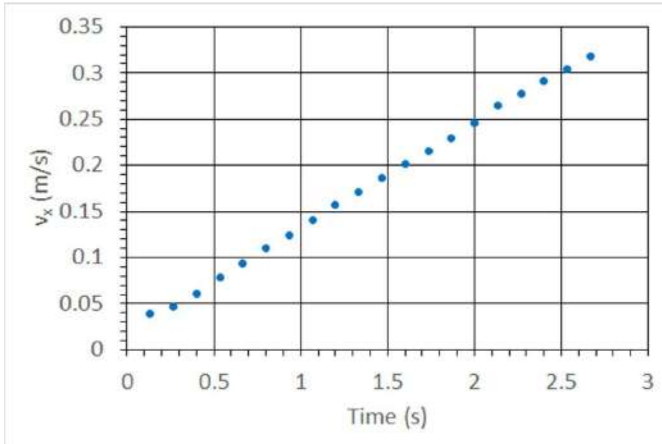
c. Compare the outcome of the two methods. Do your two measurements agree within expected uncertainties? Explain. Discuss what assumptions you made to implement each mathematical method and how these assumptions might impact the results you found.

4.4.16 Explain

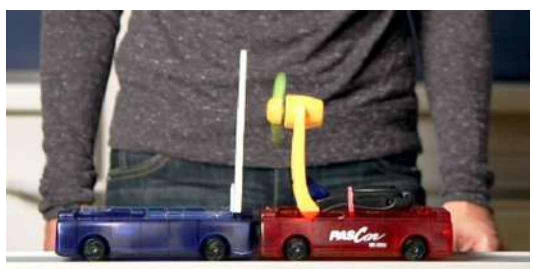
Class or lab: *Equipment per group:* none.

Imagine that you have two low friction carts to carry out the following three experiments. You fix a vertical board on cart A and a battery-operated fan on cart B. As the fan blades on cart B rotate, they exert a constant force on the air.

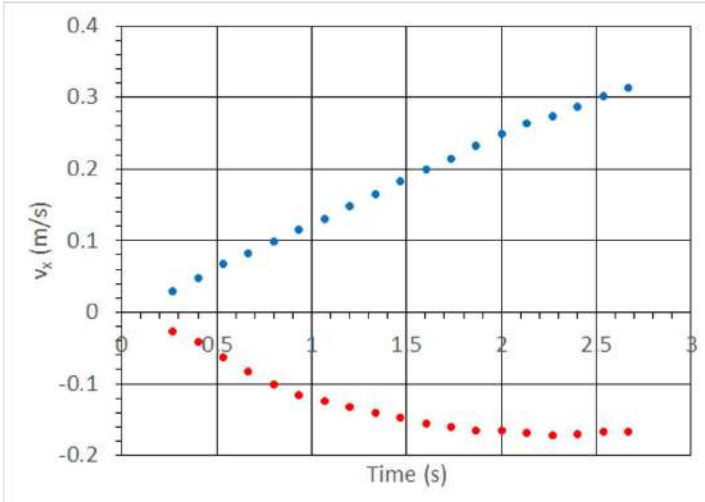
Experiment 1: You put cart B on the track and switch on the fan. While the cart is moving to the right, you record the video [https://mediaplayer.pearsoncmg.com/assets/_frames.true/sci-phys-egv2e-alg-4-4-16a]. Analyze the video frame by frame and produce the velocity-versus-time graph of the cart's motion (alternatively use the graph of the motion of cart B shown below; the *x* -axis points to the right.).



Experiment 2: You put both carts on the track, connect cart A and cart B together (using Velcro) and switch on the fan (see the figure below). The air pushed by the fan on cart B is blowing toward the vertical board on cart A, but the carts remain at rest.



Experiment 3: You repeat Experiment 2 but this time you separate the carts so they can move independently. While the carts are moving, you record the video [https://mediaplayer.pearsoncmg.com/assets/_frames.true/sci-phys-egv2e-alg-4-4-16b]. Analyze the video frame by frame and produce the velocity-versus-time graph of the carts' motions (alternatively use the graphs of the motions of cart A (in yellow) and cart B (in blue) below).



a. Explain the outcome of each experiment using Newton's laws. Show how the outcomes of the first two experiments help you explain the outcome of the third experiment.

b. Draw qualitative force-versus-time curves that show the time dependence of the sum of the forces exerted on each cart (draw both curves on the same graph).

c. Eugenia says: "The outcome of Experiment 3 violates Newton's third law." What might have led Eugenia to this conclusion? Do you agree or disagree with her? If you disagree, what would you say to Eugenia to convince her that Newton's third law is not violated in this experiment?

4.5 Projectile motion

4.5.1 Observe and find a pattern

***PIVOTAL* Lab or Class:** *Equipment per group:* whiteboard and markers, basket ball [or any other ball]. Video alternate (may be better for LRM with 100+ students): [https://mediaplayer.pearsoncmg.com/assets/_frames.true/sci-phys-egv2e-alg-4-5-1]

The goal of the experiment is for you or any member of your group to run at constant speed and while running throw the ball up so that the ball lands in your hands when it comes down. You can take a video of the person/people who did it successfully and carefully analyze the motion of the ball. Do the analysis together with your group on a whiteboard.

a. Observe the motion of the ball and the person, and describe what you observe in simple words.

b. Observe the motion of the person with respect to the floor. Draw a motion diagram representing the motion of the person. Describe in words the motion of the person relative to the floor.

c. Observe the motion of the ball with respect to the person. (It is helpful if you can step your video frame by frame.) Draw a motion diagram representing the motion of the ball with respect to the person. Describe in words the motion of the ball relative to the person.

d. Observe the motion of the ball with respect to the floor. What pattern do you see? What can you say about the motion of the ball and the person with respect to each other that is always true? Draw a motion diagram representing the motion of the ball relative to the floor.

e. How is the motion diagram you constructed in part d. related to the motion diagrams in parts b. and c.? Is there a relationship? What is it? Work with your group members to come up with an explanation for the direction of the throw that lets the ball land successfully in the runner's hands.

4.5.2 Test your idea

Lab: *Equipment per group:* whiteboard and markers, small balls, projectile launcher, meter stick.

a. Work with the members of your group to design an experiment to test the explanation that you devised in Activity 4.5.1 part e.

b. Once you have designed the experiment, make a prediction of the outcome based on the explanation under test and write it on the whiteboard. Is the prediction based on the explanation?

c. Conduct the experiment and record the outcome.

d. What is your judgment about the explanation you were testing?

4.5.3 Test an idea

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

You friends came up with an idea to explain the patterns in their experiments in Activity 4.5.1. They said that the runner needed to throw the ball exactly upwards with respect to herself because the vertical and horizontal motions of the ball are independent of each other. Use this explanation to predict the outcome of the following experiment, then watch the video, describe the outcome, and draw a conclusion about the explanation.

Testing experiment	Prediction	Outcome
At time zero, ball 1 is dropped. Simultaneously, ball 2 is shot horizontally when a compressed spring is released. Which ball hits the surface first? [See the figure in the Testing Experiment Table 4.6, page 103 in the textbook.]	Make sure you draw motion diagram(s) on your whiteboard to justify the prediction in terms of the idea you're testing	[https://mediaplayer.pearsoncmg.com/assets/_frames.true/sci-phys-egv2e-alg-4-5-3]
Conclusion		

4.5.4 Represent and reason

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

You throw a tennis ball as a projectile. Draw an arrow or arrows representing its instantaneous velocity and acceleration and the force or forces exerted on the ball by other objects when at the four positions: before it reaches the top of its flight, right at the top, falling back down, and landing (at the moment it touches the ground).

4.5.5 Real-life application

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

A stunt motorcyclist plans to ride horizontally off a 30 m (90 ft) high cliff at a speed of 10 m/s. She plans to place a pool of water on the flat ground beneath the cliff to land in.

a. Where should she place the pool so that she lands in it?

b. Make a list of assumptions you made for your calculation in part a.

c. Give her advice on which way she should move the position of the landing pool if any of the assumptions you made were not valid.

4.5.6 Application experiment: Launch the ball into the trash-can on the first try

Lab: *Equipment per group:* whiteboard and markers, projectile launcher, ball, meter sticks, c-clamp, masking tape, paper, carbon paper. Equipment for the room: 1 small trash can or bucket.

Part I.

Design an experiment to estimate the launch speed of the ball using the hardest setting of your launcher.

a. Describe your experiment. Draw a clearly labeled sketch of your experimental set-up.

b. List the sources of experimental uncertainty. List steps you will take to minimize these uncertainties. (Should you take one measurement or multiple measurements? Can you eliminate time from your measured quantities?)

c. Perform the experiment. Record the data in appropriate formats.

d. Clearly describe your mathematical procedure for calculating the launch speed.

e. Calculate the launch speed of the ball and check your result with an instructor before you go on to part II. Remember to report your final result *with* its uncertainty.

Part II.

First call an instructor and they will set the launch system at a specific angle that you will have to use for your launch.

a. Use the c-clamp to clamp your launcher to the edge of your lab table or the side bench, aiming out toward the center of the room, and set the launcher at the angle provided by the instructor.

b. Use the speed you measured in part I, and other quantities that you can measure, to estimate how far away (in the horizontal direction) you need to place the bin so that you can launch the ball into the bin on the first try. Remember to show and explain your calculations in your report, including a picture with a coordinate system and equations.

c. What assumptions did you make? Which of these assumptions is the most important for your experiment? How will you tell?

d. Discuss: Which way should you move the bin (closer to/further from the launcher) to take account of those assumptions if they were not valid?

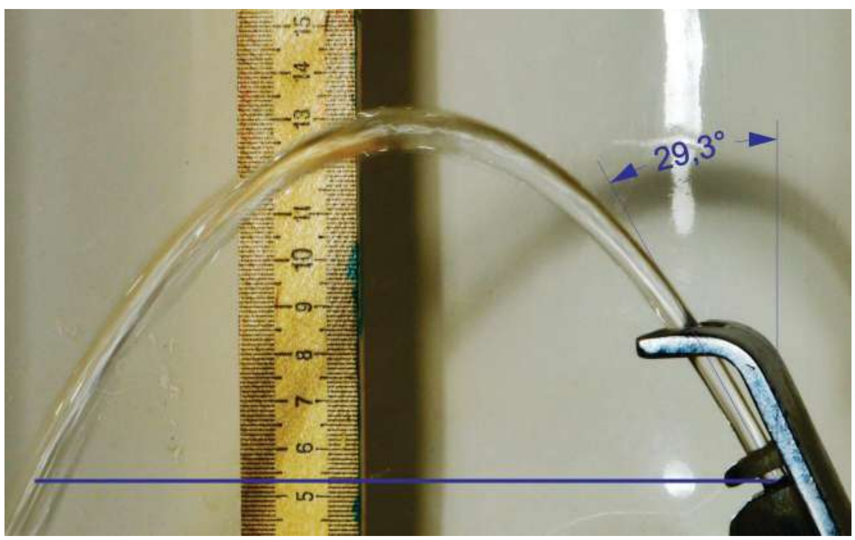
e. Show your calculation to your instructor and then perform the experiment. (Launch the ball into the bin.) NOTE: you only get *one* shot.

f. Remember to write a conclusion: Did the ball land in the bin or not? If not, why not? List all the different pieces of knowledge you had to apply in order to perform this experiment successfully.

4.5.7 Real-life application

Class or lab: *Equipment per group:* water fountain, camera and meter stick (for the lab) or the photo below (for the class); whiteboard and markers.

Obtain a photo of a steady jet from a water fountain or use the photo below. Estimate the speed of water in the jet. Indicate any assumptions that you made and evaluate the result.

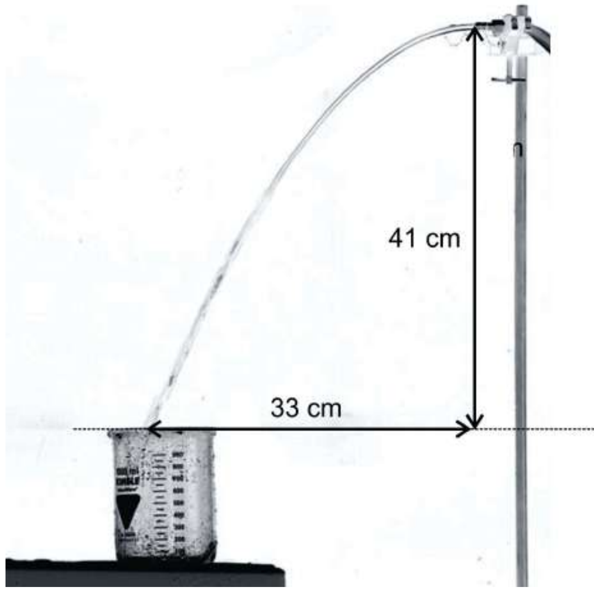


Units on the meter stick are centimeters.

4.5.8 Real-life application

Class: *Equipment per group:* photos below; whiteboard and markers.

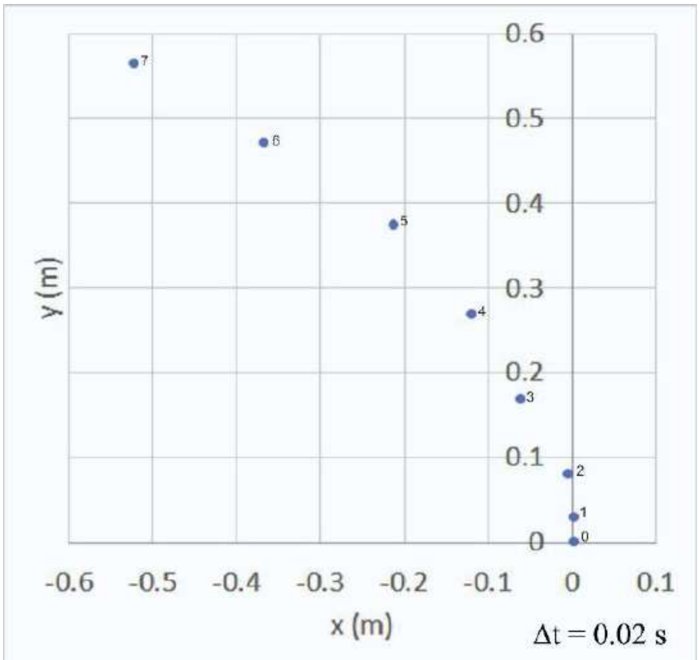
The photo below shows a steady water jet coming from a 5.5-mm diameter nozzle. The water from the jet fills a 900-mL beaker in 35 seconds. Estimate the speed of water at the nozzle. Indicate any assumptions that you made.



4.5.9 Real-life application

Class: *Equipment per group:* photo and graph below; rulers, whiteboard and markers.

A small version of a trebuchet (see the photo on the right) was used to launch a ball (see the slow motion video [https://mediaplayer.pearsoncmg.com/assets/_frames.true/sci-phys-egv2e-alg-4-5-9]). The figure below shows a two-dimensional motion diagram of the ball during the launch (the data were obtained from the video). The coordinate system is shown in the photo. The time interval between two successive points is 0.020 s.



a. Based on the motion diagram, estimate at what time the trebuchet arm stopped exerting a force on the ball (at $t = 0$ the ball was at the 0 mark). Include uncertainty in your answer. Explain how you made the estimate.

b. Estimate the launch speed of the ball (the speed of the ball when it loses contact with the arm) and the angle above the horizontal at which the ball was launched.

c. Estimate the distance from the trebuchet at which the ball landed on the ground. Indicate any assumptions that you made.

d. Your friend says that the trebuchet arm exerts a constant force on the ball during the launch. Can you reject his hypotheses based on the data given above? Explain.

4.5.10 Reading exercise

Read Section 4.5 in the textbook and answer Review Question 4.5.

4.6 Starting and stopping a car

4.6.1 Reading exercise

Read Section 4.6 in the textbook and answer Review Question 4.6.

4.6.2 Real-life application

PIVOTAL Class: *Equipment per group:* whiteboard and markers. Equipment for the room: 1 bicycle (not essential, but very useful for visualization).

Imagine your professor is pedaling their bicycle from a standstill, going faster and faster (i.e., they are speeding up). Consider your professor and their bicycle as the system.

a. Compare the *magnitude and direction* of the frictional force exerted by the road on (i) the back wheel of the bicycle, and (ii) the front wheel of the bicycle.

b. Is the frictional force exerted by the road on the front and/or back wheel static or kinetic? Discuss. How can you tell whether the friction is static or kinetic?

c. Explain what object is exerting an unbalanced force on what part of the system that allows the system to accelerate. (Remember you should treat your prof. and their bicycle as your system.)

4.6.3 Real-life application

Class: *Equipment per group:* whiteboard and markers. Equipment for the room: 1 bicycle (not essential, but very useful for visualization).

Imagine your professor is freewheeling (not pedaling) on their bicycle at 20 mph when they pull the front brake and slow down to a stop. Consider your professor and their bicycle as the system.

a. Compare the *magnitude and direction* of the frictional force exerted by the road on (i) the back wheel of the bicycle, and (ii) the front wheel of the bicycle.

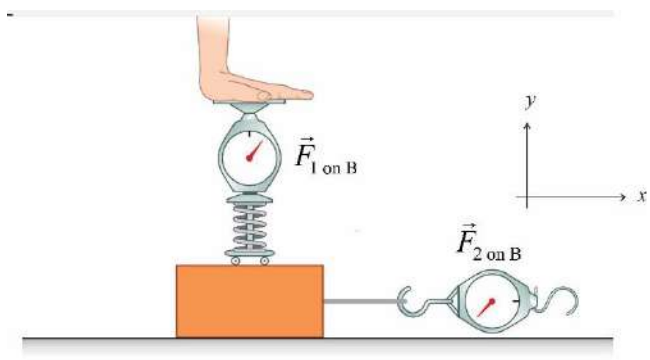
b. Is the frictional force exerted by the road on the front and/or back wheel static or kinetic? Discuss. How can you tell whether the friction is static or kinetic?

c. Explain what object is exerting an unbalanced force on what part of the system that allows him/her to slow down. (Remember you should treat your prof. and their bicycle as your system.)

4.6.4 Linearize

Class: *Equipment per group:* none.

We use a string attached to a spring scale to pull a wooden block. The mass of the block is unknown and it does not change during the experiment. We push down on the block with a spring that exerts a series of downward forces $\vec{F}_{1 \text{ on B}}$ on it. For each of these downward forces, we use the pulling string and spring scale to determine the magnitude of the maximum force $\vec{F}_{2 \text{ on B}}$ that we can exert on the block in the horizontal direction before the block starts sliding. The downward pushing spring is on wheels to prevent it from exerting horizontal forces on the block.

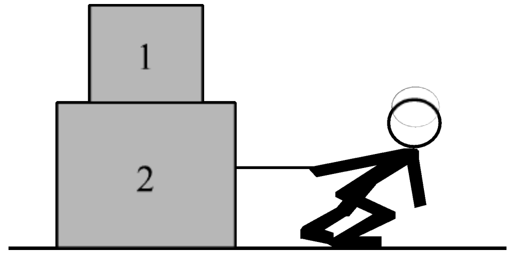


Using the measurements in the table, determine the coefficient of static friction between the block and the table, and the mass of the block.

$F_{1 \text{ on B}}$ (N)	$F_{2 \text{ on B}}$ (N)
0.0	1.2
1.0	1.8
2.0	2.2
3.0	2.6

4.6.5 Regular problem

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



Solve this problem together with your group: Block 1 has a mass of 8 kg and block 2 has a mass of 12 kg. The coefficient of static friction between block 1 and block 2 is $_s$=0.4. The coefficient of kinetic friction between block 2 and the ground is $_k$=0.2. A light rope is attached to block 2 and a person pulls the rope. What is the maximum possible force that the person can exert on block 2 so that block 1 does not slip off block 2? Hints: (i) which way will block 1 slip relative to block 2, if it slips? (ii) Draw separate force diagrams for blocks 1 and 2 and be *very careful* to identify all objects interacting with the object of interest. As you work, compare your force diagrams and ideas with another group.