Chapter 6

Impulse and Linear Momentum

6.1 Mass accounting

6.1.1 Observe and explain

Lab or class: *Equipment per group:* whiteboard and markers, plastic water bottle filled with water, camera (phone), digital scale

Take a plastic bottle full of water and put it on the scale. Record its mass and take a photo. Then place the bottle in the freezer until the water inside is completely frozen solid. Next, take the bottle out and place it on the scale again.

a. What happened to the mass of the bottle? What happened to its volume (use the photo you took before to compare)?

b. Can you explain the changes in the mass (if the mass changed)?

c. How can you test your explanation?

6.1.2 Represent and reason

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

a. Imagine that you have 10 oranges in a bag. You give 3 to your friend Darla and 2 to your friend Paolo. With your group, discuss the changes in the mass of oranges considering just the oranges in the bag as the system. Then repeat the same analysis for the system that contains the bag, oranges, and your friends. Can you say that the mass of the system is constant in both cases? Can the mass disappear?

b. Now read the textbook Section 6.1 and draw two bar charts on a whiteboard for the process described above. Bar chart 1 considers the bag + oranges as the system, and bar chart 2 considers the bag + oranges + your friends as the system. Are the two bar charts consistent with each other?

6.1.3 Reason

Class: *Equipment per group:* whiteboard and markers

Photosynthesis: The complex process of photosynthesis can be summarized in terms of the conversion of carbon dioxide and water into glucose and oxygen:

$$CO_2 + H_2O \rightarrow C_6H_{12}O_6 + O_2$$

Note that atoms are not created or destroyed in the reactions, they just change their "partners." Work together with your group on a whiteboardto show how the above equation should be corrected so that mass will be constant.

6.1.4 Reason

Class: *Equipment per group:* none

Discuss with your group:

a. Is the smaller mass of burned charcoal embers compared to the mass of the starting briquettes a violation of mass conservation? Explain.

b. Describe a testing experiment you could perform to test whether mass is conserved (but not necessarily constant) or whether it is not conserved in a combustion process. Make sure you describe both predicted outcomes: 1. What should happen in your experiment if mass is conserved? 2. What should happen in your experiment if mass is not conserved? Summarize your group's ideas on a whiteboard.

6.1.5 Reading exercise

Read Section 6.1 in the textbook and answer Review Question 6.1.

6.2 Linear momentum

6.2.1 Observe and find a pattern

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

Imagine observing the following four experiments occurring with a two-object system. Two carts (the system consists of *both* carts) move on a dynamics track:

a. Cart A (200 g) moving left at constant 0.70 m/s speed hits identical cart B (200 g) that is stationary. Cart A stops and cart B starts moving at speed 0.70 m/s to the left.

b. Cart A loaded with blocks (total mass of the cart with blocks is 400 g) moving left at 0.70 m/s hits stationary cart B (mass 200 g). After the collision, both carts move left: cart B at speed 0.86 m/s and cart A at speed 0.27 m/s.

c. Cart A (200 g) with modeling clay attached to the front moves left at 0.70 m/s. Identical cart B (200 g) moves right at constant speed 0.70 m/s. The carts collide, stick together thanks to the clay, and stop.

d. Repeat experiment c. but this time cart A is loaded (total mass of the cart with blocks is 400g). After the collision both carts stick together and travel left at speed 0.23 m/s.

For *each* experiment, work with your group and use a whiteboard to sketch the process before the collision and after the collision, and create a table like the one that follows to help you determine if anything is the same before and after the collision for the two-cart system. (Use the table below to look for quantities.)

Possible physical quantity	**Mass** m	**Speed** v	**Velocity** $\vec{v}$	**Mass times speed** mv	**Mass times velocity** $m\vec{v}$	**Mass times speed squared** mv^2
Cart A (*before* collision)						
Cart B (*before* collision)						
Combined physical quantity for Cart A & Cart B (add line 1 and line 2 for each quantity)						

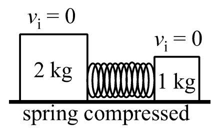
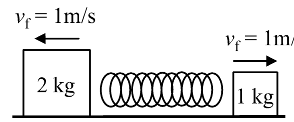
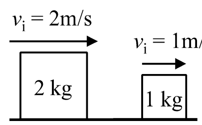
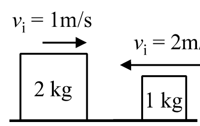
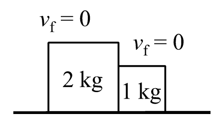
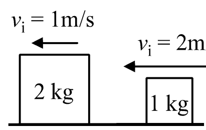
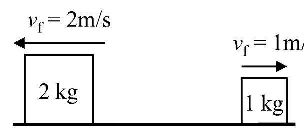
Cart A (*after* collision)						
Cart B (*after* collision)						
Combined physical quantity for Cart A & Cart B (add line 1 and line 2 for each quantity)						

After you come up with a physical quantity that is the same before and after each collision, decide whether this quantity remains constant in all four experiments. Compare your results with those from another group.

6.2.2 Reason

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

The initial and final situations for four processes are shown below. Work with your group members to decide which ones *are* possible according to your knowledge of the physical quantity you came up with? Explain your reasons. The numbers indicate the masses and the speeds of the blocks.

	Initial state	Final state
a.		
b.		
c.		
d.		

6.2.3 Test your idea

PIVOTAL ***Class or lab:*** *Equipment per group:* whiteboard and markers, laptop

The photo below shows Bor and Eugenia on rollerblades. Your goal is to use the physical quantity you've come up with in the previous experiment to make a prediction of the ratio of Bor's and Eugenia's speeds after Eugenia pushes Bor. Bor's mass is 70 kg, Eugenia's mass is 54 kg.

a. What is the physical quantity (that stays the same for a system before and after a collision) that you are using to make a prediction?

b. Use this quantity and information provided to make a numerical prediction of the ratio of Bor's and Eugenia's speeds after Eugenia pushes Bor.

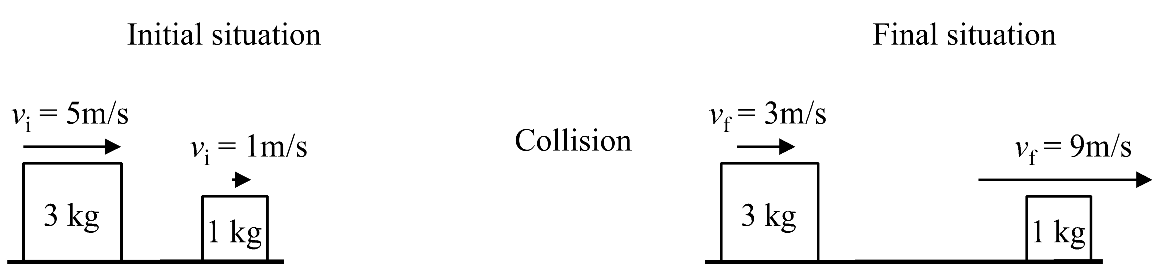
c. Run the video [https://mediaplayer.pearsoncmg.com/assets/_frames.true/sci-phys-egv2e-alg-6-2-3] and take appropriate measurements by stepping the video frame by frame. Record and tabulate your data appropriately and include estimates of the uncertainties of your measured quantities.

d. Make a judgment about whether the experimental measurement agrees with your prediction for the ratio of the two speeds. What can you say about the new physical quantity that you used to make the prediction?

6.2.4 Evaluate

Class: *Equipment per group:* whiteboard and markers

Suppose that your friend showed you a picture of the experiment that she conducted in her lab (see below). Discuss with your group: Do you believe that this is a real experiment? Why or why not? The left block has three times the mass of the right block.



6.3 Impulse and momentum

6.3.1 Derive

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

a. Suppose you push a 1 kg cart with your hand, exerting a constant force of 5 N for a time of 5 seconds. If the cart starts from rest and there is no friction, what is the final speed of the cart (after the 5 seconds have elapsed)?

b. Now do the same thing in symbols: Your hand pushes horizontally on a cart of mass *m*, exerting a force $\vec{F}_{\text{H on C}}$ for a time interval $(t_f - t_i)$. The forces exerted downward on the cart by Earth and upward on the cart by the track are balanced. The track is very smooth, so we assume that $\vec{F}_{\text{H on C}}$ is the only force exerted in the *horizontal* direction on the cart. The cart is initially moving at velocity $\vec{v}_{\text{Ci}}$ at the clock reading t_i and, after the pushing, is moving at velocity $\vec{v}_{\text{Cf}}$ at the clock reading t_f. Write an expression for $\vec{v}_{\text{Cf}}$ in terms of $\vec{v}_{\text{Ci}}$, the unbalanced force $\vec{F}_{\text{H on C}}$ and the time interval $(t_f - t_i)$.

c. Rearrange your expression from **b.** to show that:

$$\vec{F}_{\text{H on C}}\left(t_{\text{f}} - t_{\text{i}}\right) = m_{\text{C}}\vec{v}_{\text{Cf}} - m_{\text{C}}\vec{v}_{\text{Ci}}$$

The term on the left $\vec{F}_{\text{H on C}}\left(t_{\text{f}} - t_{\text{i}}\right)$ is called the *impulse* $\vec{J}$ due to the external force $\vec{F}_{\text{H on C}}$ during that time interval. The term on the right $m_{\text{C}}\vec{v}_{\text{Cf}} - m_{\text{C}}\vec{v}_{\text{Ci}}$ is called the *change in the momentum* of the cart.

d. Suppose that friction is not negligible. How would you modify the expression for the impulse on the cart to include both the effect of the hand and of friction?

e. Consider a *new* situation. Suppose a cart is already moving (with no friction present); the cart's forward velocity is decreased due to the force exerted by a hand pushing lightly back on it. How would you write the expression for the impulse due to that force?

6.3.2 Reason

Class: *Equipment per group:* whiteboard and markers

Work together with your group members to answer the following questions: Eugenia and David are both wearing rollerblades. Eugenia's mass is two-thirds that of David. Initially they are at rest, with one standing behind the other. Use your knowledge of momentum to answer the questions that follow for **both** of the following two scenarios. (Assume that friction is negligible):

Scenario 1: Eugenia stands behind David and abruptly pushes him toward the right.

Scenario 2: David stands behind Eugenia and abruptly pushes her toward the right.

a. Eugenia is the system; what happens to her momentum? Consider movement toward the right to be positive.

b. David is the system; what happens to his momentum? Consider movement toward the right to be positive.

c. Eugenia and David are the system; what happens to their total momentum? Consider movement toward the right to be positive.

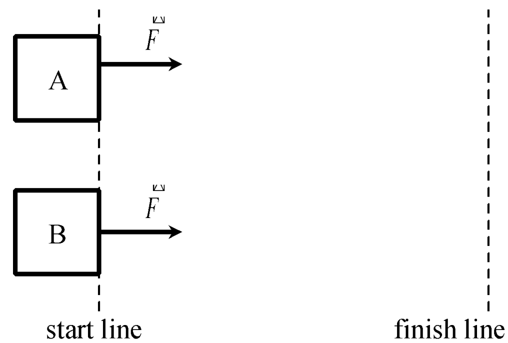
d. Now use Newton's second and third laws and kinematics to make predictions about Eugenia's and David's final velocities in the experiment: What are the directions and the ratio of the speeds of Eugenia and David just after Eugenia stops pushing David toward the right?

6.3.3 Reason

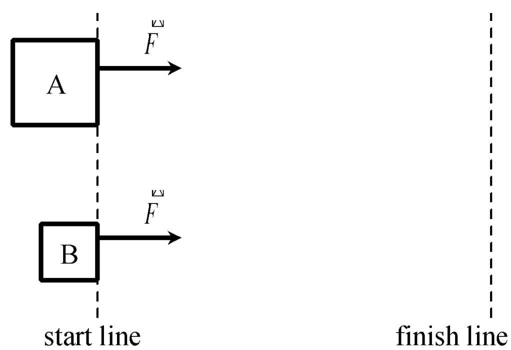
Class: *Equipment per group:* whiteboard and markers

Answer the following questions on a whiteboard, working with your fellow group members.

a. You continuously push equally hard on identical blocks A and B from the start line to the finish line. Block B is initially at rest whereas block A is initially moving right. Which block has the greater change in momentum in moving from the start to the finish line? Explain your answer.



b. Suppose that both blocks in the previous problem start at rest, but that block A has four times as much mass as block B. Which block has the greater change in momentum in going from the start to the finish line? The blocks are pushed with equal-magnitude forces.



6.3.4 Represent and reason

Class: *Equipment per group:* whiteboard and markers

Together with your group, consider the following scenario: A ball falls toward the floor and rebounds upward.

a. On a whiteboard, draw an arrow representing its velocity just before touching the floor; another arrow for its velocity just after leaving contact with the floor on the rebound; and a velocity change vector.

b. What is the direction of the net average impulse (net average force times the time interval during which it is exerted) that the floor exerts on the ball?

c. Construct a force diagram on your whiteboard for the ball when it is in contact with the floor. Make the force arrows the correct relative magnitudes (consistent with the velocity change).

6.3.4 Reading exercise

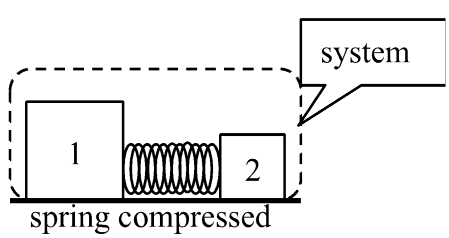
Work through Section 6.3 in the textbook and answer Review Question 6.3.

6.4 The generalized impulse-momentum principle

6.4.1 Represent and Reason

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

Blocks 1 and 2 rest on a horizontal frictionless surface. A compressed spring of negligible mass separates the blocks. Block 1 has twice the mass of block 2. When the spring is released, the blocks are pushed apart. Work together with your group to answer the questions below concerning this process.



a. Compare the momentum magnitudes of block 1 and of block 2 after the spring is released.

b. Compare the combined momentum of both blocks before the spring is released and the combined momentum after the spring is released.

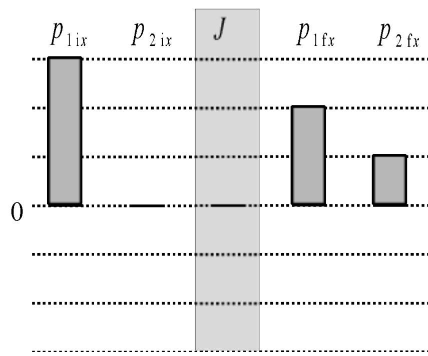
c. Compare the speed of block 1 to that of block 2 after the spring is released.

d. Together with your group, read Physics Tool Box 6.1 in Section 6.4 of the textbook. Represent the process using a qualitative impulse-momentum bar chart for a system consisting of the spring and two blocks. Draw your bar chart on a whiteboard and compare your ideas with another group. Do any other objects exert external forces on the system objects—especially in the horizontal direction?

6.4.2 Bar chart Jeopardy

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

The bar chart on the right represents an impulse-momentum process. Work with your group to answer the following questions concerning this process.



a. Describe in words and sketch a physical process that the bar chart might describe. Be specific.

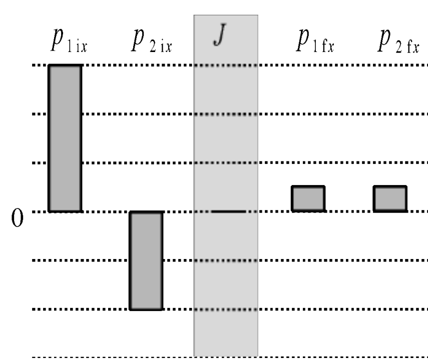
b. Describe what would happen to p_{1fx} if p_{2fx} was positive three units instead of positive one unit.

c. Describe what would happen to p_{1fx} if p_{2fx} was positive four units instead of positive one unit.

6.4.3 Bar chart Jeopardy

Class: *Equipment per group:* whiteboard and markers

The bar chart on the right represents an impulse-momentum process. Work with your group to answer the following questions concerning this process.



a. Describe in words and sketch a real-life physical process that the bar chart might describe. Be specific.

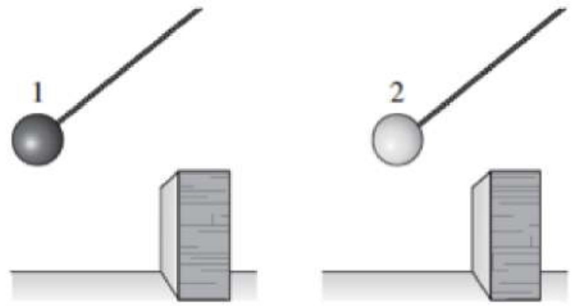
b. Describe what would happen to p_{1fx} and p_{2fx} if p_{2ix} was negative three units instead of negative two units. Assume that the final momenta of the two objects are equal but different from before.

c. Describe what would happen to p_{1fx} and p_{2fx} if p_{2ix} was positive one unit instead of negative two units. Assume that the final momenta of the two objects are equal but different from before.

6.4.4 Represent and reason

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

Two equal-mass balls made of different materials swing down at the ends of strings from equal heights and hit identical bricks. Ball 1 bounces back, whereas Ball 2 flattens and stops when it hits the brick. Ball 1 knocks the brick over and Ball 2 does not. Work with your group and use your knowledge of impulse-momentum to explain why. Specify the system. On your whiteboard, include a bar chart of the process that is consistent with your chosen system.



6.4.5 Represent and reason

Class: *Equipment per group:* whiteboard and markers

Imagine that you drop a ball from a window. After the ball falls 2.0 m, it has acquired considerable speed. Use a whiteboard and work with your group to answer the following questions:

a. Draw an impulse-momentum bar chart for the process using the ball as the system.

b. Draw a bar chart using the ball *and* Earth as a system.

c. Explain why the ball speeds up as it falls, using your knowledge of impulse and momentum.

d. Explain why the ball speeds up as it falls, using your knowledge of Newton's laws.

e. Discuss the differences in the bar charts because of the choice of system.

f. Discuss whether the explanations based on impulse-momentum and Newton's laws are consistent with each other.

6.4.6 Represent and reason

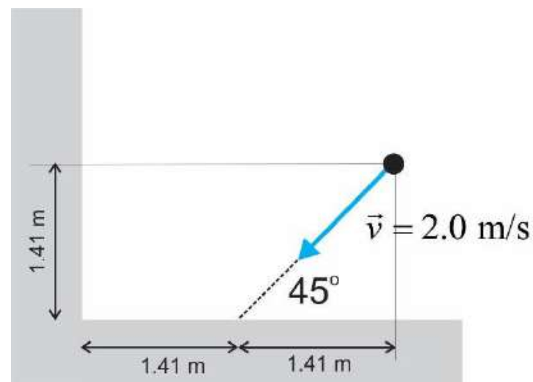
PIVOTAL ***Class:*** *Equipment per group:* whiteboard and markers

You are wearing rollerblades and holding a heavy medicine ball. You push off the floor once and continue rolling at constant speed across the floor. Then you drop the medicine ball. Collaborate with your group to describe everything you can about momentum in this process using words, bar charts, and mathematics. Decide what your system is and what the initial and final states are. Put your ideas on a whiteboard and compare your work with another group.

6.4.7 Represent and reason

Class: *Equipment per group:* whiteboard and markers

A puck is moving on horizontal ice toward a corner made of two concrete walls. The figure shows the top view of the puck at time $t = 0$. The speed of the puck is 2 m/s. Assume that the puck rebounds from the wall with the same speed as before the collision.



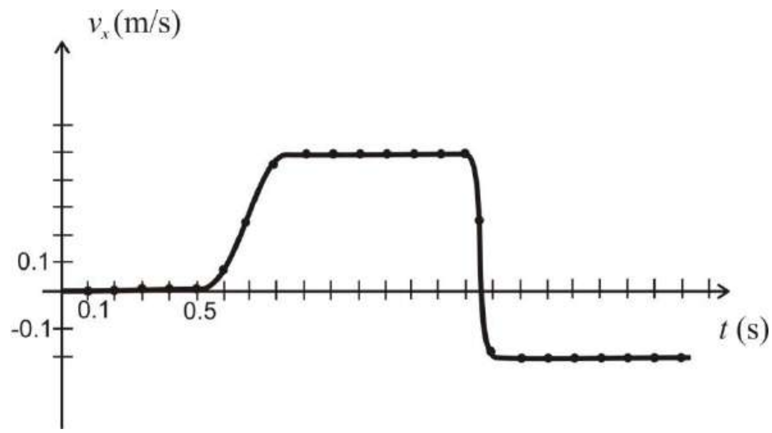
a. Draw v_x-versus-time and v_y-versus-time graphs for the motion of the puck during the time interval $0 \leq t \leq 3.0$ s.

b. For each collision with the wall, draw the momentum bar charts (before/after the collision, separate for the *x*-direction and *y*-direction), taking the puck as a system.

6.4.9 Reason

Class: *Equipment per group:* whiteboard and markers

Elizabeth pushes cart A, which is initially at rest, along a horizontal track toward cart B, which is also initially at rest. Before Elizabeth started pushing the cart, Daniel had started recording the motion of cart A using a motion detector. He obtained the following velocity-versus-time graph for cart A:



a. Estimate the clock reading when the carts collided.

b. Based on the data from the graph, can you estimate the ratio of the average force exerted by Elizabeth on cart A and the force exerted by cart A on cart B during the collision? If you think you can, determine the ratio. If you think you cannot, what additional data you would need to be able to determine the ratio?

c. Elizabeth says that the frictional forces exerted on the cart A are negligible. Describe which features of the graph support the validity of her assumption.

6.4.10 Reading exercise

Use the material in Sections 6.1-6.4 of the textbook to explain the difference between the terms *conserved* and *constant*. Give an example of when some quantity is conserved but not constant in a particular process. Think of money – can it be treated as a conserved quantity?

6.5 Skills for analyzing problems using impulse and momentum

6.5.1 Problem solving strategy

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

Work with your group members to solve the following problem using the steps of the problem solving strategy outlined below. Then compare your work to the solution in Worked Example 6.4. After you correct missing parts, solve the *Try It Yourself* problem at the end of the example.

A 0.020-kg bullet traveling horizontally at 250 m/s embeds in a 1.0-kg block of wood resting on a table. Determine the speed of the bullet and wood block together immediately after the bullet embeds in the block.

Sketch and translate • Sketch the initial and final states and include appropriate coordinate axes. Label the sketches with the known information and identify the unknowns. Decide on the object of reference. • Choose a system based on the quantity you are interested in, for example, a multi-object isolated system to determine the velocity of an object, or a single-object non-isolated system to determine an impulse or force. Sometimes it is better to decide what is in your system and then identify initial and final states.	
Simplify and diagram • Determine if there are any external impulses exerted on the system. Drawing a force diagram could help determine the external forces and their directions. • Draw an impulse-momentum bar chart for the system for the chosen direction(s) to help you understand the situation, formulate a mathematical representation of the process, and evaluate your results.	
Represent mathematically • Use the bar chart to apply the generalized impulse-momentum principle along the chosen axis. Each nonzero bar becomes a nonzero term in the equation. The orientation of the bar determines the sign in front of the corresponding term in the equation. • Remember that momentum and impulse are vector quantities, so include the plus or minus signs of the components based on the chosen coordinate system.	
Solve and evaluate	

• Insert the known information to determine the unknown quantity. • Check if your answer is reasonable with respect to sign, unit, and magnitude. Also make sure it applies for limiting cases, such as objects of very small or very large mass.	

6.5.2 Equation Jeopardy 1

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

Talk with your group members to devise a problem that is consistent with the mathematical description of a process shown below. Multiple processes may be described by the equation. Put your ideas on a whiteboard and compare what you got with another group.

$$(24\ \text{kg})(-2.0\ \text{m/s})+(30\ \text{kg})(+3.0\ \text{m/s})=(24\ \text{kg}+30\ \text{kg})v$$

6.5.3 Equation Jeopardy 2

Class: *Equipment per group:* whiteboard and markers

Talk with your group members to devise a problem that is consistent with the mathematical descriptions of a process shown below. Multiple processes may be described by the equations. Put your ideas on a whiteboard and compare what you got with another group.

$$F(t_\text{f}-t_\text{i})=(0.010\ \text{kg})\left[(+100\ \text{m/s})-(+300\ \text{m/s})\right]$$

where

$$(t_\text{f}-t_\text{i})=\frac{(0.040\text{m}-0)}{\dfrac{(+100\text{m/s})+(+300\text{m/s})}{2}}$$

6.5.4 Evaluate the solution

Class: *Equipment per group:* whiteboard and markers

The problem: A 0.40-kg bundle of unexploded fireworks moves horizontally to the right at speed 2.0 m/s. It creates a small explosion, which breaks the bundle into two pieces. The first piece with 10% of the mass moves right at 40 m/s. What is the velocity of the remaining piece?

Proposed solution:

$$(0.40\text{kg})(2.0\text{m/s}) = (0.04\text{kg})(40\text{m/s}) + (0.40\text{kg})v$$

or

$$v = \frac{(0.80\text{kg}\cdot\text{m/s} - 1.6\text{kg}\cdot\text{m/s})}{(0.40\ \text{kg})} = 2\text{m/s}$$

a. Work with your group members to identify any missing elements/errors in the solution.

b. Provide a corrected solution if you find missing elements or errors.

6.5.5 Evaluate the solution

Class: *Equipment per group:* whiteboard and markers

The problem: A 2000-kg pickup truck traveling at 20 m/s collides with a stationary 1000-kg compact car. The vehicles lock together and skid on a level surface for 16 m until stopping. Determine the coefficient of kinetic friction between the tires and the road.

Proposed solution:

Part I: The collision

Momentum conservation: $(2000\text{kg})(20\text{m/s}) = (3000\text{kg})v$

$$v = 13.3\text{m/s}$$

Part II: Skidding to a stop

Stopping time: $(t_\text{f} - t_\text{i}) = \dfrac{(x_\text{f} - x_\text{i})}{v} = \dfrac{16\ \text{m}}{13.3\text{m/s}} = 1.2\text{s}$

Stopping force: $$f_k = \frac{(mv_f - mv_i)}{(t_f - t_i)} = \frac{(2000\ \text{kg})(20\ \text{m/s})}{(1.2\ \text{s})} = 33{,}300\ \text{N}$$

Coefficient of kinetic friction: $$\mu_k = \frac{f_k}{N} = \frac{f_k}{mg} = \frac{(33{,}300\ \text{N})}{(3000\ \text{kg})(9.8\ \text{N/kg})} = 1.1$$

a. Identify any missing elements/errors in the solution.

b. Provide a corrected solution if you find missing elements or errors.

6.5.6 Design an experiment

Lab: *Equipment per group:* whiteboard and markers, steel ball and a ball made of modeling clay, a force probe connected to a computer.

Set up the software so that the computer screen displays a force-versus-time graph for a collision (the force that the probe exerts on a ball during a collision in which the probe stops the ball).

a. Work with your group to design a series of experiments to investigate the differences between the collision of the steel ball with the probe and the clay ball with the probe.

b. Perform the experiments and record the results.

c. Explain the results using your knowledge of impulse and momentum.

6.5.7 Reason

Class: *Equipment per group:* whiteboard and markers

a. Discuss with your group members: Describe a situation where the sum of the forces exerted on a system by other objects in the horizontal direction is not zero but momentum is constant in the vertical direction.

b. Describe a situation where the sum of the forces in the vertical direction is not zero but momentum is constant in the horizontal direction.

6.5.8 Reason

Class: *Equipment per group:* whiteboard and markers

Discuss with your group members: For each situation described below, indicate if it is more appropriate to use i. the generalized impulse-momentum principle or ii. the momentum constancy equation to solve the problem. Explain your choices, but do not solve the problems.

a. Estimate the speed of an initially at rest 800-kg rocket sled on a horizontal frictionless surface after its engine fires with a thrust of 2.0×10^4 N for 10 s.

b. An 1800-kg rocket sled with a 20-kg cannon ball initially travels on a horizontal surface at speed 80 m/s relative to the ground. What is the sled's speed after it ejects the cannon ball in the backward direction at a speed of –40 m/s relative to the ground?

c. A 6-kg bowling ball moving at 3 m/s hits a single 2-kg pin knocking it forward at 6 m/s. What is the speed of the bowling ball after the collision?

d. A 6-kg bowling ball moving at 3 m/s hits a single 2-kg pin knocking it forward at 6 m/s. If the collision took 0.050 s, what average force was exerted on the pin?

6.5.9 Argue

Class: *Equipment per group:* whiteboard and markers

How would you convince your friend that an air bag in a car can save a passenger's life during a head-on collision? Work with your group using a whiteboard. Try making some sort of side-by-side comparison (a collision with or without air bag) on your whiteboard. Use the Internet to get data and make as many representations as you need (equations, bar charts, words etc…). Present your argument to another group using your whiteboard.

6.5.10 Estimate

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

Collaborate with your group to estimate the fastest you can make a skateboard move across a horizontal surface by jumping off of it when it is stationary. Justify all numbers used in your estimate. What assumptions about objects, interactions, and processes involved in the situation did you make? Put all your work on a whiteboard.

6.5.11 Estimate

Class: *Equipment per group:* whiteboard and markers

Collaborate with your group to estimate the maximum speed you can get your professor to roll on roller blades by throwing a medicine ball at her (or him). S/he is originally at rest. Indicate any assumptions about objects, interactions and processes used in your estimate. Put all your work on a whiteboard.

6.5.12 Estimate

Class: *Equipment per group:* whiteboard and markers

Collaborate with your group to estimate the force that a tennis ball exerts against a practice board. Indicate any numbers used in your estimate. Note that a tennis ball flattens about one-third or more of its diameter during a collision.

6.5.13 Real-life application

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

A 1120-kg Ford Escort hits a 1420-kg Chrysler at rest. The two cars lock together and skid 12.0 m on a level surface before stopping. Police determine that the coefficient of kinetic friction between the tires and road is 0.70. Was the first car exceeding the 45 mph speed limit? This is a two-part problem. Identify the two parts of the problem and the concept used to solve each part. Represent each part in multiple ways and find the unknown initial velocity of the Ford Escort.

6.6 Jet propulsion

6.6.1 Real-life application

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

A 3000-kg spaceship travels toward the Moon at a speed of 1.5×10^4 m/s. The captain of the ship wishes to change direction by 5°. Rockets eject fuel at a speed of 3.0×10^6 m/s perpendicular to the ship's initial direction. Determine the mass of fuel that must be ejected to change course as the captain wishes. What assumptions did you make?

6.6.2. Reading exercise

Read Section 6.6 in the textbook and answer Review Question 6.6.

6.7 Collisions in two dimensions

6.7.1 Real-life application

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

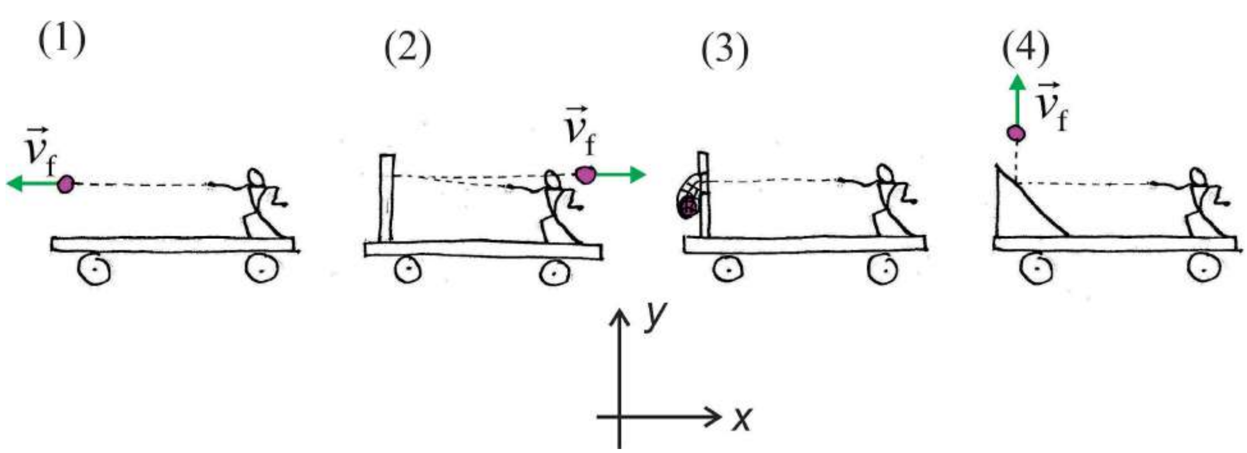
Work with your group to decide who is at fault in this car accident: You are in an automobile accident and believe the other car was traveling faster than indicated by its driver. Before the collision your 1400-kg car was traveling south at 35 mph. The other 1800-kg car was traveling west at an unknown speed (the driver claims 30 mph). After the collision, the two cars become locked together and travel in a direction 25° south of west. Was the other car exceeding the 35-mph speed limit?

6.7.2 Reading exercise

Read Section 6.7 in the textbook and answer Review Question 6.7.

6.7.3 Apply

Shawn (mass M) performs four experiments on four carts. All carts have equal masses $2M$. The carts are on a frictionless track and initially at rest. In all experiments, Shawn is standing on the cart and throws a ball of mass *m* horizontally in the negative *x*-direction, always with the same initial velocity $\vec{v}_\mathrm{i}$ (initial state). The final states are shown in the figures below. Assume $|v_\mathrm{i}| = |v_\mathrm{f}|$ in the experiments 1, 2, and 4, and the final velocity of ball 3 is zero.



a. Draw an impulse-momentum bar chart for each experiment. The system is Shawn, the cart, and the ball. Show separate bars for each object of the system.

b. For each experiment, derive an expression for the final speed of the cart in terms of relevant parameters. Discuss the direction of the final velocity.