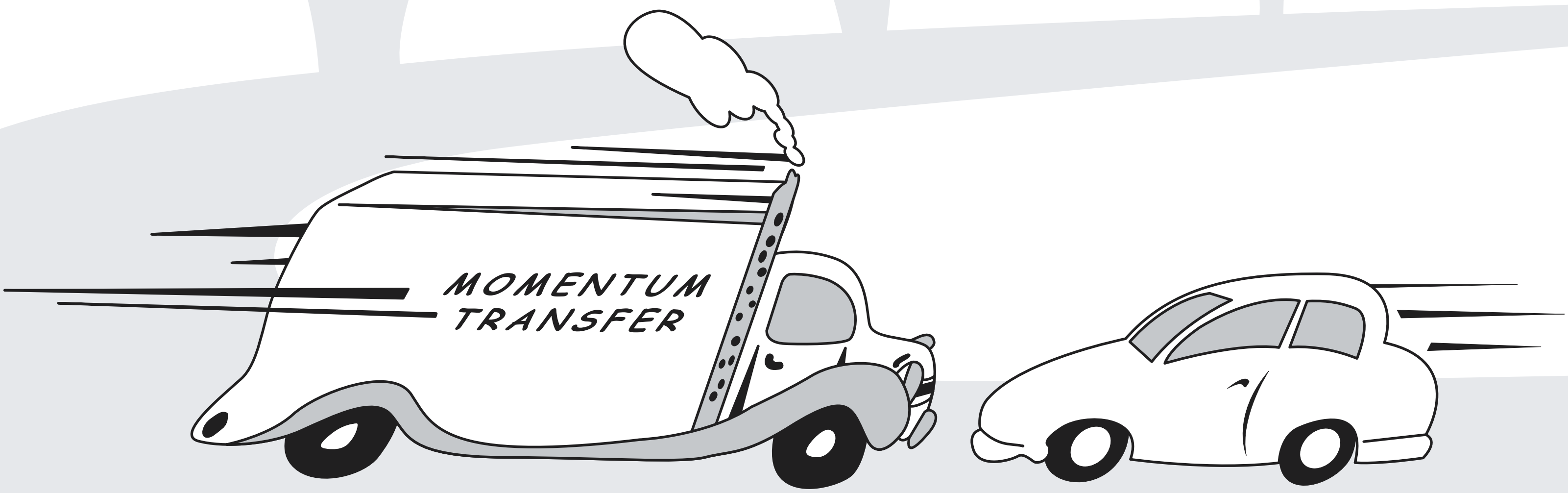
Understanding Car Crashes: It's Basic Physics!

Teacher's guide for grades 9–12
by Griff Jones, Ph.D.



This teaching guide will help you to:

- effectively present the video in your classroom
- teach hands-on "crash science" lessons
- fulfill curriculum requirements
- teach objectives that correlate with national science standards
- stimulate students' interest in modern crashworthiness

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About the Author

Griff Jones is an assistant professor at the University of Florida's P.K. Yonge Developmental Research School in Gainesville. He has directed the elementary science laboratory program and taught high school physics since 1987. He received his undergraduate degree in science from Florida Southern College in 1983 and masters (1987), specialist (1995), and doctoral (2002) degrees in science education from the University of Florida. As part of the school's innovative hands-on elementary science laboratory program, he conducts science lab activities with third, fourth, and fifth grade classes. He also teaches two classes of Honors Physics to high school juniors and seniors.

Mr. Jones has conducted more than 100 science inservice workshops/institutes at the state, national, and international levels. He has served as principal investigator and lead teacher on numerous state and federally funded science education grants from agencies including the Florida Department of Education and the National Science Foundation. He has designed science education laboratory equipment and accompanying instructional materials for Sheldon Laboratory Systems and Science Kit & Boreal Labs and has published articles regarding innovative science teaching strategies in journals including "Science and Children" and "The Science Teacher." He has consulted for numerous agencies and commercial publishers, including the federally-funded GLOBE program and Silver, Burdett, Ginn and Addison-Wesley publishing companies.

Mr. Jones has received numerous teaching awards, including "Who's Who Among America's Teachers." In 1998, he received the Presidential Award for Excellence in Science Teaching from the White House and the National Science Foundation for his work in secondary education, and the Florida Association of Science Teachers' "Outstanding Science Teacher Award" for his work with elementary students and teachers.

Graphics

The graphics used in this guide are based on designs by **Paul G. Hewitt** and are used with his permission. Clip-art versions of Paul G. Hewitt's graphics are available from **Laserpoint Educational Software, c/o "Hewitt DrewIt!", 5629 Omni Drive, Sacramento, CA 95841, fax 916/344-3233.**

Acknowledgements

The Institute would like to thank the following teachers for expert advice and assistance in developing "Understanding Car Crashes — It's Basic Physics!"

Development

Richard Halada, M.S.
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Lyle D. Roelofs, Ph.D.

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Lyle D. Roelofs, Ph.D.
Mark Twiest, Ph.D.
Marsha Winegarner, M.S.

Pilot Testing of Video

Jim Chalker, M.A.
Edwin Eckel, M.S.
Richard Halada, M.S.
Kim Freudenberg, M.Ed.
Robert A. Morse, Ph.D.
Lyle D. Roelofs, Ph.D.

How to Use this Guide

The lessons in this guide introduce students to the physics of car crashes with high-interest, grade-level appropriate activities designed to meet national science standards. Students will learn why a crash is a potentially devastating event and gain new perspective on the importance of restraint use and vehicle size. Teacher lesson plans and accompanying blackline masters for student activity sheets are provided. The lessons are intended to supplement a high school physical science curriculum with hands-on activities that demonstrate the basic physics principles of motion and relate them to car crashes.

Using the Video Worksheet

The **video worksheet** serves as an advanced organizer of the content provided in the video. Students complete the low-order questions as they watch the video. Teachers may find it beneficial to stop the video periodically for students to collaborate on the answers. Once completed, a worksheet may be used as a study guide and review sheet for the key concepts introduced in the video.

Using the Post-Video "Crash" Questions

The **post-video "crash" questions** are higher-order questions intended to stimulate discussion among students. Individual questions may be assigned to small groups for discussion, with each group responsible for presenting answers to the class for discussion.

Using the Lesson Plans

Four **teacher lesson plans** and accompanying blackline masters for **student activity sheets** are provided. The lessons are intended to supplement a high school physical science curriculum with hands-on activities that demonstrate the basic physics principles of motion and relate them to car crashes.

Lesson Format

Each lesson is organized using the same standard format and includes the following components:

Key question: states the primary focus of the activity in the form of a question that is relevant to the students' experiences. Key question may be used to initiate or conclude the activity.

Grade level: suggests appropriate grade levels.

Time required to complete lesson: estimates the range of time needed to complete the main procedure of the lesson with a class of 28–32 students. Additional time is necessary to complete Going Further activities.

National science education standards: activities correlated to content standards, grades 9–12, of the National Science Education Standards, National Academy of Sciences, Washington D.C., 1996.

Behavioral objectives: identifies desired student outcomes in the form of observable behaviors.

Background information: contains relevant background information on the science concepts explored in the activity. Key concepts and vocabulary are in boldface type.

Crash course definitions: lists and defines key science vocabulary used in the lesson.

Materials: lists all supplies needed for students working in small groups to complete the activity.

Getting ready: describes steps the teacher should take to prepare for the activity.

Procedure: includes step-by-step instructions for completing the lesson. The procedure follows the three-stage learning cycle of exploration, concept development, and application. Answers to student activity sheet questions are provided.

Extension(s): suggests extension activities that continue to make the science concepts relevant to students and introduces related concepts.

Using the website

The Insurance Institute for Highway Safety's website **(www.highwaysafety.org)** is easy to use and can provide students and teachers with a wide variety of information on the factors involved in motor vehicle crashes and how to reduce injuries.

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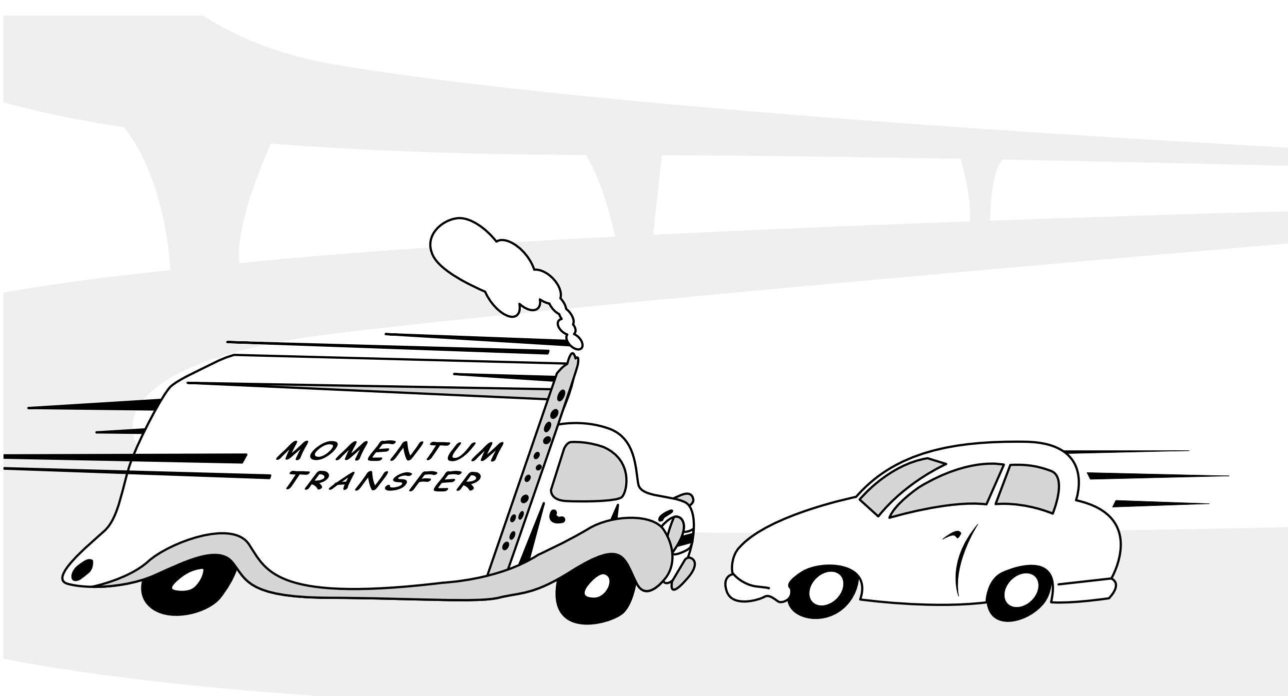
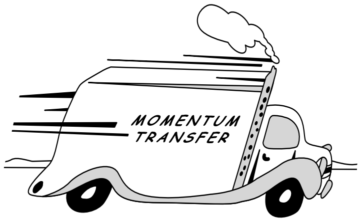




"Understanding Car Crashes It's Basics Physics"

Video Concept Organizer

Teacher Organizer Answers

TIME

Running Time:
22 minutes

Directions:
To help you remember the key physics concepts discussed while viewing the video, fill in the blanks or (circle) the correct answer.

Video Scenes & Key Concepts

Test Track Laws

2:15 — Why did the dummy get left behind? It's called __**inertia**__ , the property of matter that causes it to __**resist any change in its motion**__.

2:50 — Isaac Newton's (circle one) (**1st**) **2nd** **3rd** Law of Motion states: A body at rest remains at __**rest**__ unless acted upon by an external __**force**__, and a body in __**motion**__ continues to move at a constant __**speed**__ in a straight line unless it is acted upon by an external force.

Crashing Dummies

3:20 — Now watch what happens when the car crashes into a barrier. The front end of the car is crushing and absorbing __**energy**__ which slows down the rest of the car.

4:00 — In this case, it is the steering wheel and windshield that applies the __**force**__ that overcomes the dummy's __**inertia**__.

Crash-Barrier Chalkboard

4:35 — Newton explained the relationship between crash forces and inertia in his (circle one) **1st** (**2nd**) **3rd** Law of Motion.

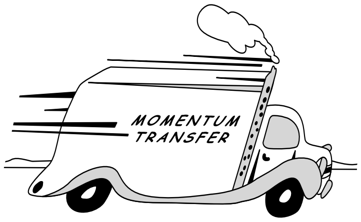
(Fill in the blanks to explain what each letter in the formula represents.)

F = __**force**__ ⟶ $F = ma$ m = __**mass**__
a = __**acceleration**__

$F = \frac{m\Delta v}{t}$ Δv = __**change in velocity**__
t = __**time or rate**__

Ft = __**impulse**__ ⟶ $Ft = m\Delta v$ $m\Delta v$ = __**change in momentum**__

"CRASH COURSE" ACTIVITY

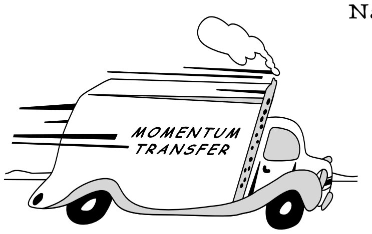


"Understanding Car Crashes It's Basics Physics"

Video Concept Organizer

Teacher Organizer Answers

TIME	
	Surfers, Cheetahs, and Elephants ...oh my!
5:20	Momentum is inertia in motion. It is the product of an object's mass and its velocity.
5:35	Which has more momentum? An 80,000 pound big rig traveling 2 mph or a 4,000 pound SUV traveling 40 mph? (circle one) Big Rig SUV (same)
	Soccer Kicks, Slap Shots, and Egg Toss
6:05	What is it that changes an object's momentum? an impulse. It is the product of force and the time for which it acts.
6:18	If the eggs are of equal mass and are thrown at the same velocity they will have the same momenta. The wall and the sheet both apply equal impulses.
6:45	The wall applies a bigger force over a shorter time, while the sheet applies a smaller force over a longer time.
7:10	With panic braking the driver stops in less time or distance and experiences more force.
	Crashing and Smashing
8:20	The second animated vehicle's front end is less stiff so it crushes two feet instead of one, causing the deceleration to decrease from 30gs to 15 gs.
9:04	Extending the time of impact is the basis for many of the ideas about keeping people safe in crashes. List three applications in vehicle or highway safety. 1. crumple zones 2. airbags 3. break-away light poles
	Conserving Momentum and Energy - It's the Law!
9:42	In a collision of two cars of unequal mass, the occupants of the lighter car would experience much higher accelerations, hence much higher forces than the occupants of the heavier car.
12:55	Motion related energy is called kinetic energy. Energy due to an object's position or conditions is called potential energy.
13:50	At what point in the pendulum's swing is its potential energy equal to its kinetic energy? mid-point When is its kinetic energy at its maximum? bottom
14:30	(Circle) the correct formula for kinetic energy (KE). KE = 1/2 m2v KE = 1/2 $2mv^2$ (KE = 1/2 mv^2) KE = 1/2 mv2



Name ______________________________ Period _______ Date _______

Student Organizer Questions

"Understanding Car Crashes It's Basics Physics"

Video Concept Organizer

TIME

Running Time:
22 minutes

Directions:
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Video Scenes & Key Concepts

Test Track Laws

2:15 — Why did the dummy get left behind? It's called __________ , the property of matter that causes it to____.

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Crashing Dummies

3:20 — Now watch what happens when the car crashes into a barrier. The front end of the car is crushing and absorbing __________ which slows down the rest of the car.

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Crash-Barrier Chalkboard

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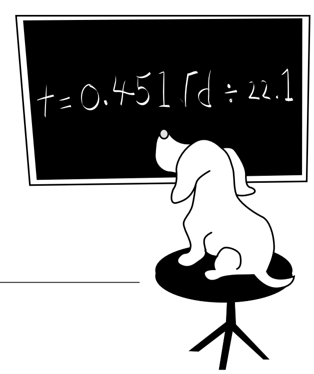
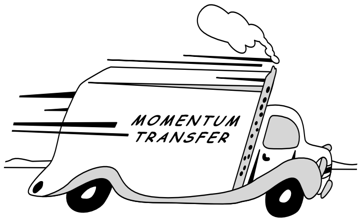
(Fill in the blanks to explain what each letter in the formula represents.)

F = _________ → $F = ma$ m = __________ a = __________

$F = \frac{m\Delta v}{t}$ Δv = t = ____________________

Ft = _________ → $Ft = m\Delta v$ $m\Delta v$ = ____________________





"CRASH COURSE" ACTIVITY

"Understanding Car Crashes It's Basics Physics"

Video Concept Organizer

Student Organizer Questions

TIME

Surfers, Cheetahs, and Elephants ...oh my!

5:20 Momentum is ______________ in motion. It is the product of an object's ______________ and its ______________.

5:35 Which has more momentum? An 80,000 pound big rig traveling 2 mph or a 4,000 pound SUV traveling 40 mph? (circle one) **Big Rig** **SUV** **same**

Soccer Kicks, Slap Shots, and Egg Toss

6:05 What is it that changes an object's momentum? ______________. It is the product of ______________ and the ______________ for which it acts.

6:18 If the eggs are of equal mass and are thrown at the same velocity they will have the same ______________. The wall and the sheet both apply equal ______________.

6:45 The wall applies a ____________ force over a ____________ time, while the sheet applies a ____________ force over a ____________ time.

7:10 With panic braking the driver stops in less time or distance and experiences more ______________.

Crashing and Smashing

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9:04 Extending the time of impact is the basis for many of the ideas about keeping people safe in crashes. List three applications in vehicle or highway safety.

1.__________________ 2.__________________ 3.__________________

Conserving Momentum and Energy–it's the Law!

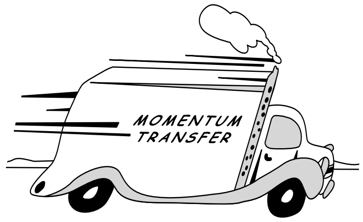
9:42 In a collision of two cars of unequal mass, the occupants of the lighter car would experience much higher ______________, hence much higher ______________than the occupants of the heavier car.

12:55 Motion related energy is called ______________. Energy due to an object's position or conditions is called ______________.

13:50 At what point in the pendulum's swing is its potential energy equal to its kinetic energy? ______________ When is its kinetic energy at its maximum? ______________

14:30 (Circle) the correct formula for kinetic energy (KE).

KE = 1/2 m2v **KE = 1/2 2mv²** **KE = 1/2 mv²** **KE = 1/2 mv2**



"CRASH COURSE" ACTIVITY

"Understanding Car Crashes It's Basics Physics"

Video Discussion Questions

Teacher Post-Video Answers

Directions:

After viewing the video, answer the following questions in the space provided. Be prepared to discuss your responses with your classmates while in small groups or as an entire class.

Post-Video "Crash" Questions

1. Ever tried to stop a 150 pound (68 kg) cannonball fired towards you at 30 mph (48 km/hr.)? No, probably not. But you may have tried to brace yourself in a car collision. How are the two situations similar?

   Both you and the cannonball have momentum based upon mass and velocity. If you are traveling 30 mph and weigh 150 pounds your momentum would equal the cannonball's. In a major collision, it is impossible to prevent injuries by bracing yourself. No matter how strong you think you are, you are not strong enough to stop your inertia during a collision.

2. Show mathematically why an 80,000 pound (36,000 kg) big rig traveling 2 mph (0.89 m/s) has the SAME MOMENTUM as a 4,000 pound (1,800 kg) sport utility vehicle traveling 40 mph (18 m/s).

   Momentum is the product of an object's mass and velocity. The formula is $p = mv$. The product of each is equivalent.

   The SI unit for momentum is the kilogram x meter/second (kg x m/s).

   Truck momentum = (36,000 kg)(0.89 m/s) = 32,000 kg x m/s

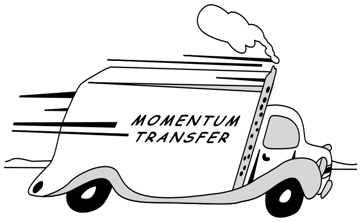
   SUV momentum= (1,800 kg)(18 m/s) = 32,000 kg x m/s

3. During the Egg-Throwing Demonstration, which egg experienced the greater impulse, the egg that hit the wall or the bed sheet? (Be careful here!) Which egg experienced the greater force of impact? Which egg experienced the greater time of impact?

   If their momenta are equal before the collisions (same mass and velocity), both eggs experience identical impulses because both are stopped by the collision.

   The egg that hit the crash barrier experienced the greater impact force due to the shorter impact time.

   The egg that collided with the bed sheet experienced the greater time of impact, thereby experiencing a smaller stopping force over a longer time interval.



"Understanding Car Crashes It's Basics Physics"

Video Discussion Questions

Teacher Post-Video Answers

4. Explain how the fortunate race car drivers survived their high speed accidents.

   The impulse that the wall applied to both cars was identical BUT remember impulse is the force of impact multiplied by the time of impact. With the fortunate driver, the identical impulse was a product of a small force extended over a long period of time.

5. Describe other examples where momentum is reduced by applying a smaller collision force over a longer impact time (or where things "give way" during a collision to lessen the impact force)?

   Answers will vary. Some examples: Bungee jumping; trampolines; trapeze safety nets; falling on grass compared to concrete; many football players prefer the "give" of natural grass to the harder artificial turf.

6. Which would be more damaging to your car: having a head-on collision with an identical car traveling at an identical speed or driving head on into the Vehicle Research Center's 320,000 pound (145,455 kg) deformable crash barrier? Explain.

   Both crashes produce the same result. Either way the car rapidly decelerates to a stop. In a head-on crash of identical cars traveling at equal speeds, the result is equal impact forces and impact times (according to Newton's Third Law of Motion), and therefore equal changes in momenta. Using a crash barrier is more cost efficient.

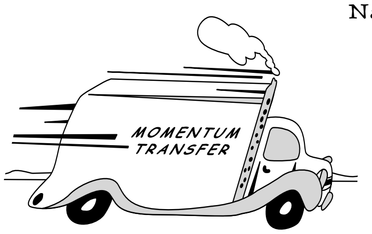
7. Show mathematically why a small increase in your vehicle's speed results in a tremendous increase in your vehicle's kinetic energy. (For example: doubling your speed from 30 mph to 60 mph results in a quadrupling of your kinetic energy.)

   The velocity is squared in the equation; therefore if the speed is first doubled then squared, its kinetic energy must quadruple to keep the equation balanced.

   $KE = 1/2\ mv^2$ $\quad$ $4KE = 1/2\ m2v^2$

8. The Law of Conservation of Energy states: energy cannot be created or destroyed; it can be transformed from one form to another but the total amount of energy never changes. Car crashes can involve huge amounts of energy. How does the crashworthiness of the car affect the transfer and transformations of the energy and, ultimately, protect the occupants?

   In a crash of a well designed car, the kinetic energy does the work that crushes the car's crumple zones. Some of the energy also becomes heat and sound generated by the crash. The safety cage must be strong enough to resist the forces that arise during the crash so that it holds its shape and allows the restraint system to do its job.



Name ______________________________Period _______ Date_______

Student Post-Video Questions

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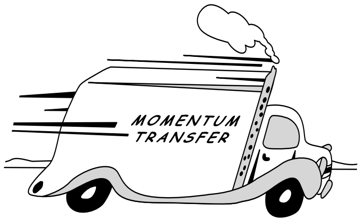

"CRASH COURSE" ACTIVITY

"Understanding Car Crashes It's Basics Physics"

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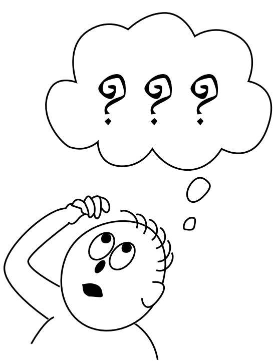
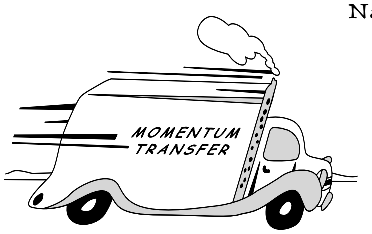


6. Which would be more damaging to your car: having a head-on collision with an identical car traveling at an identical speed or driving head on into the Vehicle Research Center's 320,000 pound (145,455 kg) deformable concrete crash barrier? Explain.

Name ______________________________Period_______ Date_______



"Understanding Car Crashes It's Basics Physics"

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7. Show mathematically why a small increase in your vehicle's speed results in a tremendous increase in your vehicle's kinetic energy. (For example: doubling your speed from 30 mph to 60 mph results in a quadrupling of your kinetic energy.)

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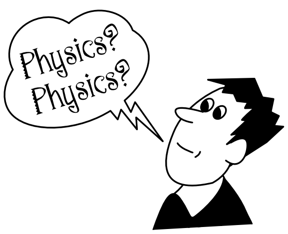

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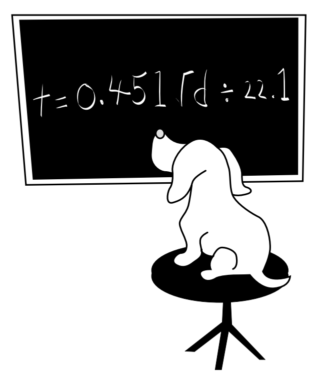
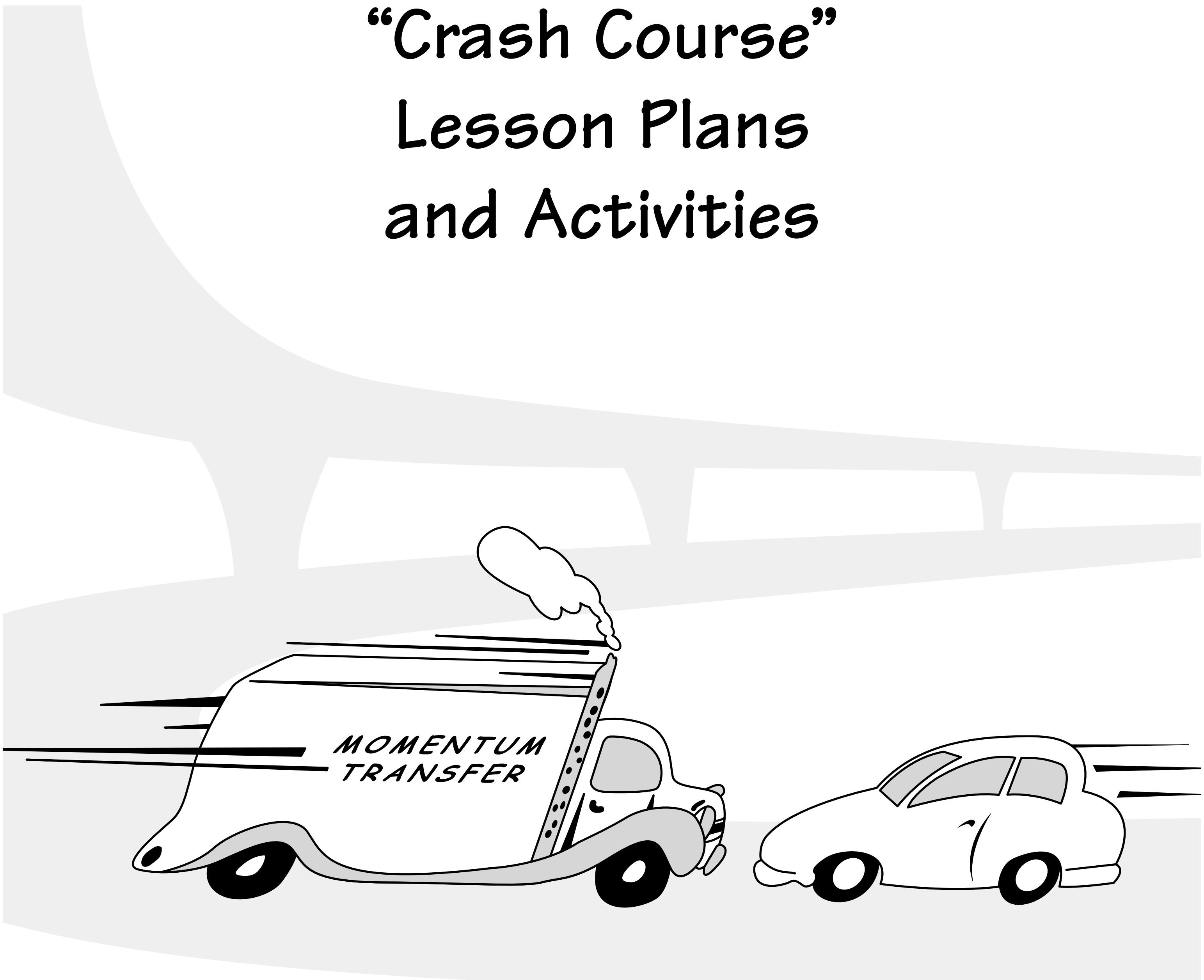


"Crash Course" Lesson Plans and Activities



"CRASH COURSE" ACTIVITY

Penny for Your Thoughts on Inertia

Crash Course Definitions

inertia: property of an object to resist any change in its state of motion

mass: quantity of matter in an object; measure of an object's inertia

Key Question(s)

- How do magicians pull a tablecloth out from under an entire set of dishes? Is it magic or science?
- How is a magician's tablecloth trick related to a crash dummy falling off the tailgate of a pickup truck as the truck accelerates?

Grade levels: 9–12
Time required: 5–10 minutes

Objectives

Students will:

- learn and apply Newton's First Law of Motion
- recognize inertial mass as a physical property of matter

National Science Education Standards

Standard A: Science as Inquiry

- Identify questions and concepts that guide scientific investigations

Standard B: Physical Science

- Motion and forces

Standard G: History & Nature of Science

- Science as a human endeavor
- Historical perspectives

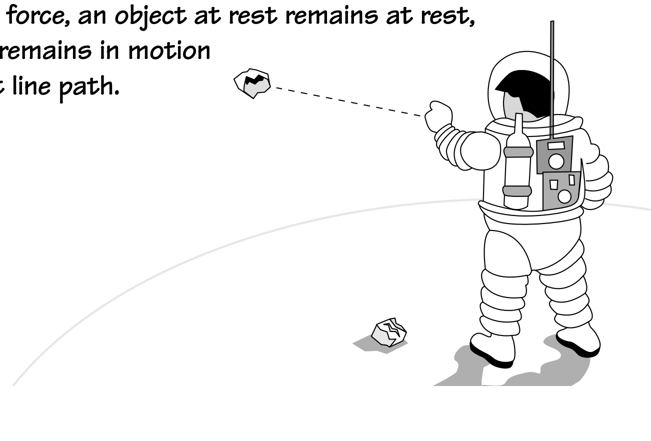
Background information

The origins of **Newton's Laws of Motion** began with the Italian philosopher Galileo Galilei (1564–1642). Galileo broke from the teachings of Aristotle that had been accepted as truth for more than 1,000 years. Where Aristotle and his followers believed moving objects must be steadily pushed or pulled to keep moving, Galileo showed with his experiments that moving things, once moving, continued in motion without being pushed or pulled (forces applied). He called the property of objects to behave this way **inertia**, which is Latin for "lazy" or "inert."

Isaac Newton, born in England on Christmas day in 1642 (the year Galileo died) refined Galileo's Principle of Inertia in terms of unbalanced forces and made it his first law of motion.

Newton's First Law of Motion

In the absence of an unbalanced force, an object at rest remains at rest, and an object already in motion remains in motion at constant speed on a straight line path.



"CRASH COURSE" ACTIVITY

Penny for Your Thoughts on Inertia

TEACHER LESSON 1

Materials needed

For each group:

- 3"x 5" index card
- plastic cup or beaker
- 1–10 pennies
- (optional) mix of dimes, nickels, quarters, half dollars

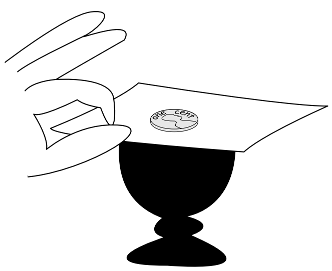
Getting ready

Assemble the materials for each group. You may wish to consider having other coins available for the groups to try. Their results may vary with the mass of the coins used. More mass results in more inertia.

Procedure

1. Cover the cup with the index card and put the penny on top of the card.
2. Challenge the students to get the penny in the cup without lifting the card and only touching it with one finger.

   Best method "Flick" the card horizontally with your forefinger.
3. After students have succeeded with one penny, challenge them to try multiple pennies and other coins.



Answers to analysis questions

1. Describe a successful technique.
   Answers will vary. See above for best method, Step 2 Procedure.
2. Why does the penny drop in the cup when the card is "flicked" away? **Very little of the sudden horizontal force from your flicking finger is transferred upward to the penny, so the inertia of the penny keeps it over the mouth of the cup. With the card no longer providing support force, the force of gravity pulls it straight down into the cup.**
3. How did the total mass of the coins used affect your success?
   They should have been more successful with more mass. More mass equals more inertia, which equates to a greater resistance to movement. But too much mass increases the force of friction beyond your horizontal flicking force and the card cannot move out from under the coins.
4. How do magicians use Newton's First Law to their advantage in pulling a tablecloth out from under an entire set of dishes?
   The heavier the plates the greater the inertia, and the better the magician's chance for success. But too much mass increases the force of friction beyond the horizontal pulling force and the tablecloth cannot move out from under the dishes.

Answers to crash questions

How is a magician's tablecloth trick related to a crash dummy falling off the tailgate of a pickup truck as the truck accelerates?

Both apply the concept of inertia. Just as inertia keeps the plates at rest as the magician pulls the tablecloth our from under them, inertia keeps the crash dummy at rest as the tailgate moves out from under it.

Name ______________________________Period _______ Date_______

STUDENT ACTIVITY 1

Penny for Your Thoughts on Inertia

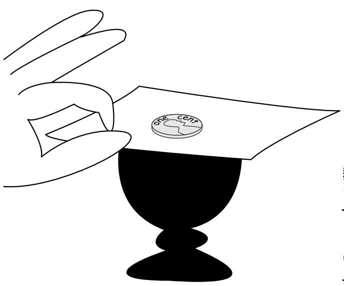
Crash test question

• How is a magician's tablecloth trick related to a crash dummy falling off the tailgate of a pickup truck as the truck accelerates?

Purpose

To explore the concept of inertia.

Materials needed



For each group:

• 3"x 5" index card
• plastic cup or beaker
• 1–10 pennies
• (optional) mix of dimes, nickels, quarters, half dollars

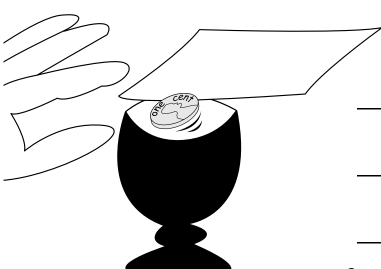
Discussion

Whether you are attempting the magician's tablecloth trick or slamming on your car brakes to avoid an accident, the laws of nature apply. Understanding nature's basic rules or PHYSICS can help improve your chances of success in either situation.

Procedure

1. Cover the cup with the index card and put the penny on top of the card.
2. The challenge is to get the penny into the cup without lifting the card and only touching the card with one finger.
3. After you have succeeded with one penny, try it with multiple pennies and other coins.

Analysis



1. Describe a successful technique.

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2. Why does the penny drop in the cup when the card is "flicked" away?

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"CRASH COURSE" ACTIVITY

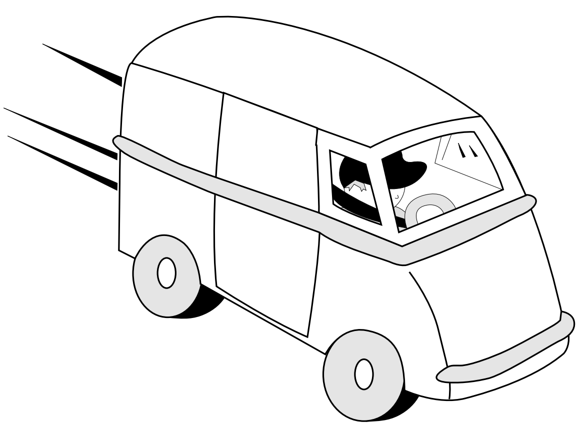
Penny for Your Thoughts on Inertia

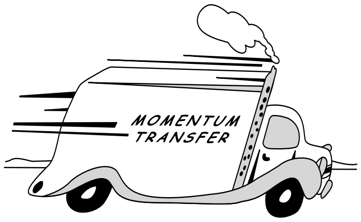
3. How did the total mass of the coins affect your success?

4. How is a magician's tablecloth trick related to a crash dummy falling off the tailgate of a pickup truck as the truck accelerates?

Crash question

How are the magician's tablecloth trick and vehicle seat belts related?





"CRASH COURSE" ACTIVITY

Momentum Bashing

TEACHER LESSON 2

Crash Course Definitions

momentum: the product of the mass and the velocity of an object (p = mv)

velocity: the speed of an object and its direction of motion

acceleration: the rate at which velocity is changing

Key question(s)

- What determines if one car has more momentum than another in a two-car collision?
- Does increasing an object's mass increase its momentum or "bashing power?"

Grade levels: 9–12
Time required: 15–20 minutes

Objectives

Students will:

- understand and apply the definition of momentum: **momentum = mass x velocity**
- conduct semi-quantitative analyses of the momentum of two objects involved in one-dimensional collisions
- describe automobile technologies that reduce the risk of injury in a collision

National Science Education Standards

Standard A: Science as Inquiry

- Identify questions and concepts that guide scientific investigations
- Design and conduct scientific investigations

Standard B: Physical Science

- Motion and forces
- Conservation of energy

Standard F: Science in Personal and Social Perspectives

- Natural and human-induced hazards

Standard G: Nature of Science

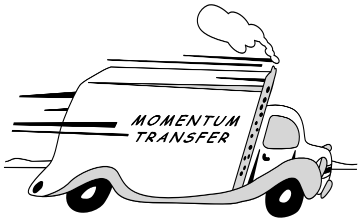
- Nature of scientific knowledge
- Historical perspectives

Background information

Science is a process that is performed not only by individuals but by a "scientific community." One of the first groups to represent the scientific community was the Royal Society of London for Improving Natural Knowledge, founded in 1660. The group evolved from informal meetings where the members discussed and performed simple scientific experiments. Led by a soon-to-be-famous member named Isaac Newton, they began to explore the topic of motion and collisions. Drawing on previous work from the "scientific community" and his own observations, Newton deduced his three simple laws of motion.

Newton's Second Law of Motion states that if you wish to accelerate something, you must apply a force to it. **Newton's First Law of Motion** then says, once an object is moving it will remain moving (unless friction or another outside force, like a wall, stops it). This is inertia of motion, or **momentum**.

The momentum of a moving object is related to its mass and velocity. A moving object has a large momentum if it has a large mass, a large velocity, or both. A marble can be stopped more easily than a bowling ball. Both balls have momentum. However, the bowling ball



Momentum Bashing

TEACHER LESSON 2

has more momentum than a marble. Momentum changes if the velocity and/or mass changes. (For more on momentum see background information from Lesson #4.)

Materials needed

For each group:

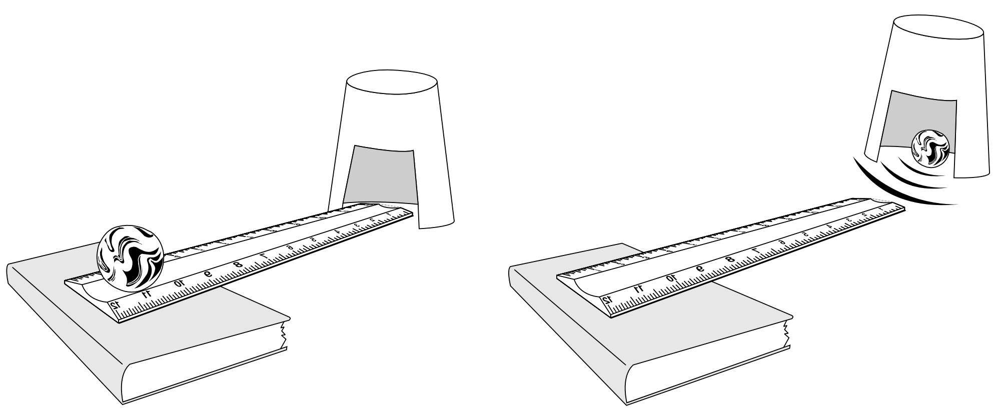
- ruler with center groove
- 4 marbles, same size
- 5-ounce (148 ml) paper cup
- scissors
- meter sticks (2)
- book to support track (3–4 cm height)

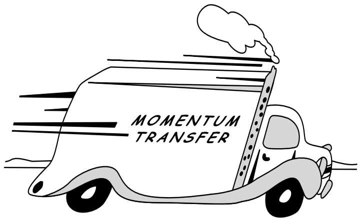
Procedure

1. Explain how scientific knowledge changes by evolving over time, almost always building on earlier knowledge (refer to background information). Tell students this lesson builds on their knowledge of force, inertia, and speed to better understand what happens in a crash. Begin the activity with a discussion of the following open-ended questions on momentum.
   - Momentum is often used by sports commentators or political analysts to describe a team's or candidate's performance, yet in physics it has a specific meaning. Can they explain the difference?
   - What determines if one car has more momentum than another in a two-car collision?
2. Explain that momentum has often been loosely defined as the amount of "oomph" or "bashing power" of a moving object. It is the measurement of an object's inertia in motion or more specifically,

   momentum = mass x velocity

   In this activity students will see how an object's mass affects its "oomph" or "bashing power."
3. Distribute "Momentum Bashing" activity sheets and supplies to each group. Instruct each group to cut the section from their paper cup and set up their ramp. Long flat tables or tile floors work well for this activity.





Momentum Bashing

TEACHER LESSON 2

4. Circulate and assist groups. Have students measure the distance the cup moves to the nearest 0.1 cm. With good techniques, this simple equipment can produce results that are consistent enough to have students conclude that increasing the number of marbles increases the bashing power or momentum (see sample data).

number of marbles	trial 1 cm	trial 2 cm	trial 3 cm
1	5.0	5.0	5.7
2	12.5	13.0	12.5
3	19.5	19.2	19.0
4	24.0	24.1	24.8

sample data for distance cup moved (with ruler height 3.0 cm)

Answers to analysis questions

1. Describe the relationship between the number of marbles hitting the cup and the distance the cup moves.
   As the number of marbles increase the distance the cup moves increases. The average increase in distance was 6.8 cm, 6.5, and 5.8 for each additional marble: 1–2, 2–3, 3–4 respectively.

Answers to crash questions

1. What determines if one car has more momentum than another in a two-car collision?
   Momentum is a product of a car's mass and velocity. A lighter car can have a greater momentum if it has a high speed compared with the heavier car.
2. Explain why an 80,000 pound big rig traveling 2 mph has the same momentum as a 4,000 pound sport utility vehicle (SUV) traveling 40 mph.
   Since momentum is the product of mass and velocity, the truck's large mass and slow speed is matched by the SUV's smaller mass but greater speed.

momentum = mass x velocity

$$p = mv$$

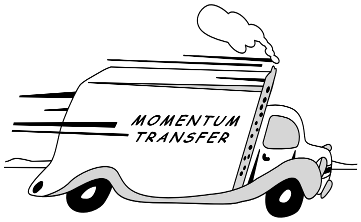
Big Rig's momentum = SUV's momentum

$$mv = mv$$

$$(80{,}000 \text{ lbs.})(2 \text{ mph}) = (4{,}000 \text{ lbs.})(40 \text{ mph})$$

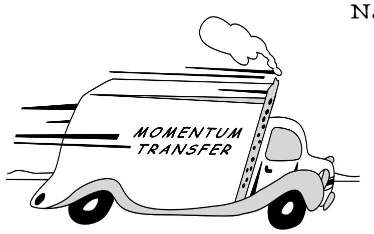
Extension(s)

1. Have students conduct further experiments with the same equipment by investigating the relationship between the height of the ruler and the distance the cup is moved. The greater release height increases the marbles' potential energy, thereby increasing their kinetic energy, speed, and momentum upon impact with the cup.
2. Have students discover the Law of Conservation of Momentum by exploring the results of two colliding objects. (See Student Activity #4).



"Crash" Notes

TEACHER LESSON 2



Name ______________________________ Period _______ Date _______

STUDENT ACTIVITY 2

Momentum Bashing

Crash test question(s)

- What determines if one car has more momentum than another in a two-car collision?
- Does increasing an object's mass increase its momentum?

Purpose

- To determine if increasing mass increases momentum
- To describe automobile technologies that reduce the risk of injury in a collision

Materials needed

For each group:

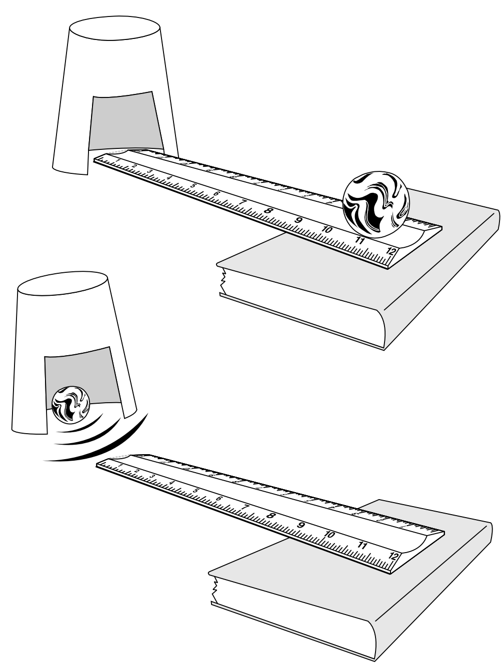
- ruler with center groove
- 4 marbles, same size
- 5-ounce (148 ml) paper cup
- scissors
- meter sticks (2)
- book to support track (3–4 cm height)

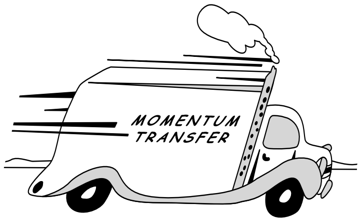
Discussion

To better understand what happens in a crash, it helps to see how force, inertia, and speed are related in a property called momentum. The amount of momentum, often referred to as "oomph" or "bashing power," that an object has depends on its mass and its velocity. In this activity you will investigate how an object's mass affects its "bashing power!"

Procedure

1. Cut a 3.0 cm square section from the top of the paper cup.
2. Place the ruler with one end on a textbook (approximately 3.0 cm height) and the other end resting on the desk.
3. Place the 3.0 sq. cm opening of the cup over the end of the ruler resting on the desk.
4. Place a meter stick along side the cup to measure the distance it moves.
5. Position ONE (1) marble in the groove at the ruler's maximum height.



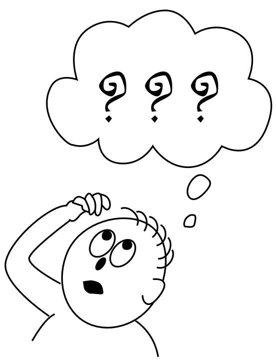


Momentum Bashing

STUDENT ACTIVITY 2

6. Release the marble and observe the cup.
7. Measure the **distance** the cup moved (to the nearest 0.1 cm).
8. Perform three (3) trials for 1, 2, 3, and 4 marbles and average the results. **Record** these measurements in the data table below.

number of marbles	measured distance cup moves (cm) trial 1	trial 2	trial 3	average distance cup moves (cm)
1				
2				
3				
4				



Analysis

1. Describe the relationship between the number of marbles hitting the cup and the distance the cup moves.

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Crash questions:

1. What determines if one car has more momentum than another in a two-car collision?

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2. Explain why an 80,000 pound big rig traveling 2 mph has the same momentum as a 4,000 pound sport utility vehicle (SUV) traveling 40 mph.

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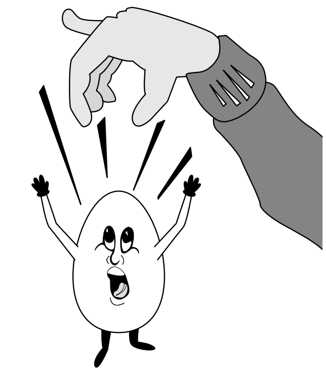
TEACHER LESSON 3



Egg Crash! Designing a Collision Safety Device

Key question(s)

- How do people survive major collisions?
- How does physics explain the effectiveness of seat belts and airbags?

Grade levels: 9–12
Time required: 50 minutes

Crash Course Definitions

impulse: product of force and time interval during which the force acts; impulse equals change in momentum, $F\Delta t=\Delta(mv)$

impact: qualitative term for force

Objectives

Students will:

- describe a collision in terms of momentum changes and impulse
- design, build, test, and evaluate a safety device to protect an egg during a collision

National Science Education Standards

Standard A: Science as Inquiry

- Identify questions and concepts that guide scientific investigations
- Design and conduct scientific investigations

Standard B: Physical Science

- Motion and forces

Standard E: Science and Technology

- Abilities of technological design
- Understanding about science and technology

Standard F: Science in Personal and Social Perspectives

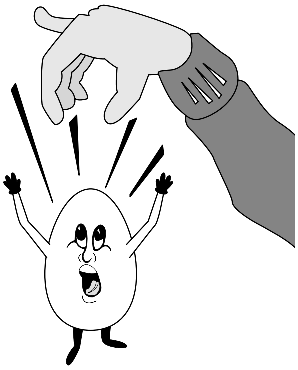
- Natural and human-induced hazards

Background information

When Newton described the relationship between force and inertia, he spoke in terms of two other physics concepts: momentum and impulse. Newton defined momentum as the product of an object's mass and velocity (see Lesson #2). Newton defined impulse as the quantity needed to change an object's momentum.

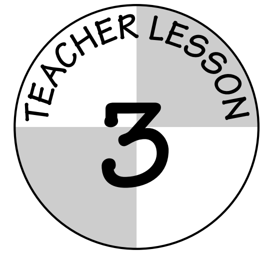
To change an object's momentum either the mass or the velocity or both change. If the mass remains constant, then the velocity changes and acceleration occurs. In his second law, Newton said in order to accelerate (or decelerate) a mass, a force must be applied. The way it's often expressed is with the equation **F=ma.** The force "F" is what's needed to move mass "m" with an acceleration "a." The greater the force on an object, the greater its acceleration, or the greater its change in velocity, and therefore, the greater its change in momentum. How long the force acts is also important. Apply the brakes briefly to a coasting car and you produce a change in its momentum. Apply the same braking force over an extended period of time and you produce a greater change in the car's momentum. So to change something's momentum both force and time are important. The product of force and the time it is applied is called **impulse**.

impulse = force x time interval



"CRASH COURSE" ACTIVITY

Egg Crash! Designing a Collision Safety Device



The greater the impulse exerted on an object, the greater its change in momentum. The amount of damage in a collision is related to the time during which the force stopped the object. Seat belts and airbags stop occupants with less damage by applying a small force over a large time interval.

Materials needed

For each group:

- copier paper, 10 sheets (8 1/2"x11")
- masking tape, 1.0 meter
- scissors, one pair

For the Egg-Crash Tests:

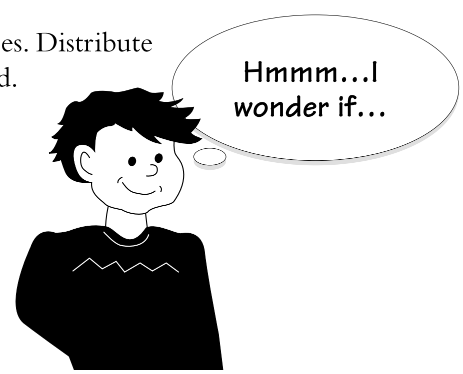
- eggs, one raw, grade A, medium or large egg per team (1–2 dozen)
- newspaper, 15–20 sheets
- meter sticks, (2–3)
- ladder, 2 meters tall (approx. 6 ft.)
- hard-surfaced floor, walkway, or playing surface (e.g. basketball court)

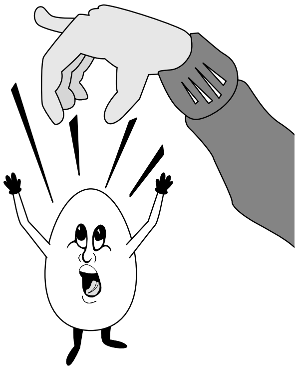
Getting ready

Separate paper into stacks of 10 sheets each. Prepare a "crash site" to test students' projects by spreading newspaper on the floor to cover an area approximately one square meter. Place a ladder next to the "crash site."

Procedure

1. Ask students to think about how people survive major vehicle collisions. Explain that scientists and engineers apply the laws of physics to reduce damage to both cars and passengers. Explain that during this activity, students will be working in groups to design, build, test, and evaluate a "safety device" (in the form of a landing pad) to protect a raw egg during a collision with a hard surface (floor).
2. Divide students into groups of two or three and distribute paper (10 sheets per group), masking tape (1 meter per group) and scissors to each group.
3. Review "Collision Safety Device" or landing pad design, building, and testing parameters with students (see "Egg Crash!" Student Activity Sheet #3). Remind students that their device must protect the egg from repeated collisions, with each experiencing a greater change in momentum.
4. Allow students 20 minutes to build their devices. Distribute eggs to students after the time limit has expired. Do not allow any pre-testing of devices.



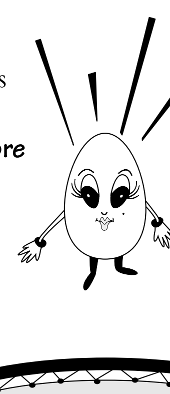


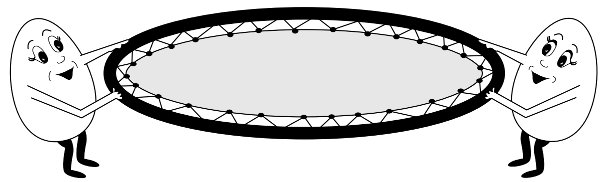
Egg Crash! Designing a Collision Safety Device

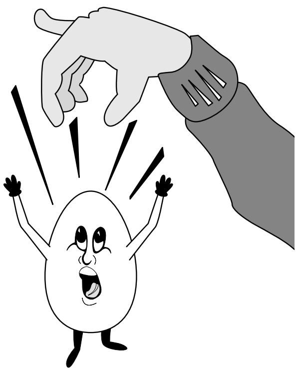
5. Determine the order in which teams are to drop or ask for teams to volunteer. Complete drops for round one before beginning round two with surviving eggs. **Suggested drop heights for rounds: 1.0 m, 1.5 m, 2.0 m, 2.5 m.**
6. Before beginning the final round, conduct a brief whole-class discussion addressing the following questions:
   - Which device do you predict to win and why?
     Answers will vary. Challenge students to relate the functioning of the devices to similar situation from their prior experience. Students may refer to interactions in which one object has more "give" than another. For example: falling on grass rather than concrete; or, when jumping from an elevated position down to the ground, bending your knees when your feet make contact with the ground instead of keeping your legs straight.
   - Why does a surface with more "give," like their Collision Safety Device, produce a safer fall?
     To bring the egg to a stop, the floor or the paper device must provide an impulse, which involves two variables—impact force and impact time. Since impact time is longer on the paper device, a smaller impact force results. The shorter impact time on the floor results in a greater impact force.
7. After the superior Collision Safety Device has been determined, have students complete the Analysis and Crash Questions.

Answers to crash questions

1. Explain how your Collision Safety Device is similar to an airbag in preventing injuries. Use the terms momentum, impulse, impact force, and impact time in your response.
   To bring the egg to a stop, the paper device must change the egg's momentum by providing an impulse, which involves two variables—impact force and impact time. Since impact time is longer on the paper device, a smaller impact force results. The shorter impact time on the floor results in a greater impact force. Airbags stop occupants with less damage by applying a small force over a large time interval.
2. Compare the impulses, impact forces, and impact times of the following: Race Car #1 crashes to a stop by hitting a wall head on; Race Car #2 crashes to a stop by skidding a great distance along a wall.
   Assuming both cars have equal momentum before the crash, both race cars experience the SAME impulse or change in momentum since they both crash to a stop. Race Car #1 experiences a big impact force over a short impact time. Race Car #2 experiences small impact force over a longer time of impact.







Egg Crash! Designing a Collision Safety Device

TEACHER LESSON 3

3. List other vehicle safety devices that reduce the impact force by increasing the time of impact.
   frontal crumple zones, padded dashboards, bumpers, collapsible steering columns
4. According to the National Highway Traffic Safety Administration thousands of people are alive today because of their airbags. Explain why airbags are NOT alternatives to seat belts but rather are intended to be used WITH seat belts to increase safety.
   Designed to work with seat belts, airbags provide additional protection, especially to people's heads and chests, in serious crashes. If there is hard braking or other violent maneuvers before the crash, the lap/shoulder belts keep people in position where there is still space for the airbags to inflate between the occupants and the hard interior surfaces. Belts also provide important protection in nonfrontal crashes. According to the Insurance Institute for Highway Safety, deaths in frontal crashes of cars with airbags are reduced by about 26 percent among drivers and 14 percent among passengers.

Extension(s)

1. Have students explore the Insurance Institute for Highway Safety's website (www.highwaysafety.org) to answer the following questions about airbags:
   - How serious does a frontal crash have to be for an airbag to inflate?
   - Are there any problems with airbags?
   - Can they injure people? How? Who is at greatest risk?
   - Should people at risk get an on/off switch for their airbags?
2. Have students videotape (either live or from television), explain, and present sequences that illustrate various interactions that effectively reduce the force by increasing the time.

Possible interactions:

- bungee jumping
- circus trapeze safety net
- boxing match (see Figure 1)
- egg toss into a bed sheet (see video, have two students hold a sagging bed sheet while another student throws an egg into the sheet)
- egg toss game (wearing lab aprons and safety goggles, pairs of students toss eggs back and forth at successively greater distances; unbroken egg caught at greatest distance wins. Note: record for Mr. Jones' classes is 31 m.)

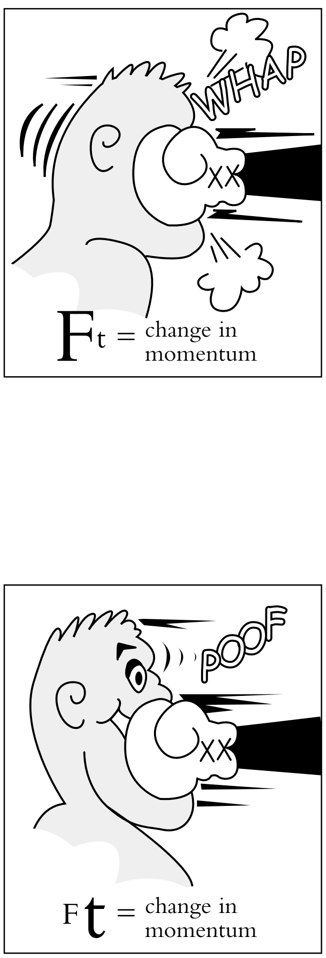
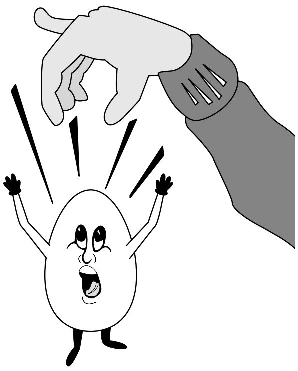


figure 1



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STUDENT ACTIVITY 3

Egg Crash! Designing a Collision Safety Device

Crash test question(s)

- How do people survive major collisions?
- How does physics explain the effectiveness of seat belts and airbags?

Purpose

- To design, build, test, and evaluate a landing pad or "safety device" to protect an egg during a collision with a hard surface
- To describe a collision in terms of changing momentum, impulse, impact force, and impact time

Materials needed

For each groups of two or three students:

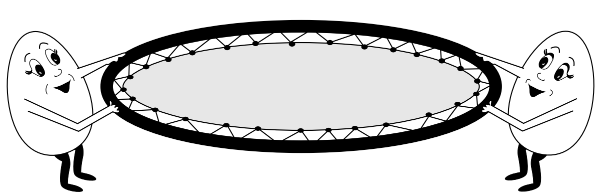
- copier paper, 10 sheets (8 1/2" x 11")
- masking tape, 1.0 meter
- scissors, one pair

Discussion

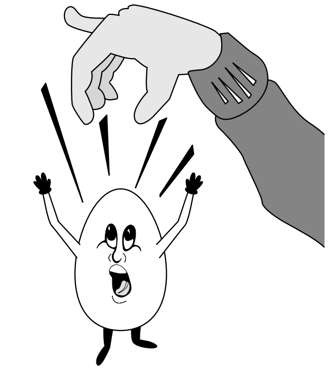
How do people survive major vehicle collisions? Scientists and engineers apply the laws of physics to reduce damage to both cars and passengers. During this activity, you will work in groups to design, build, test, and evaluate a "collision safety device" (in the form of a landing pad) to protect a raw egg during a collision with a hard surface. Hopefully, this process will help you discover the physics underlying some of the "EGGcellent" safety devices in a car!

Procedure

Using no more than 10 sheets of paper, one meter of masking tape and following the parameters listed on the back of this sheet, design, build, and test a landing pad/"collision safety device" that will protect an egg when dropped from ever increasing heights.



"CRASH COURSE" ACTIVITY

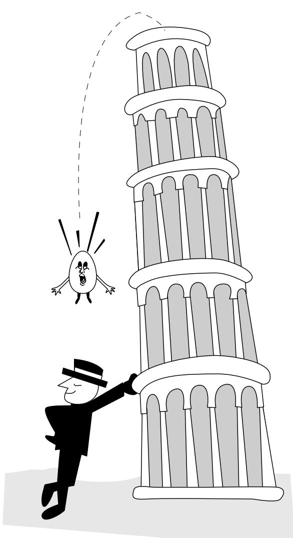


STUDENT ACTIVITY 3

Egg Crash! Designing a Collision Safety Device

EGG "Collision Safety Device" Parameters

1. Groups may use less, but no more than 10 sheets of paper.
   - Report to the teacher the amount of paper used to build your safety device. In the event of a tie, the device constructed with fewest sheets of paper will be declared the superior safety device.
2. Collision Safety Devices must be free-standing. Teams cannot support their devices by holding them or taping them to another structure.
3. Nothing may be attached to the egg.
4. Scissors may not be part of the Collision Safety Device.
5. Dropping height is measured from the bottom of the egg, at the release point, to the top of the Collision Safety Device.
6. Eggs will be dropped by a member of the Device's design team.
7. Eggs that miss the Collision Safety Device when dropped are eliminated.
8. Eggs will be inspected before and after each drop and must not show any cracks.
   - Eggs that survive the initial impact but roll off their device and break are eliminated.
   - Teams that break their egg by accident or carelessness are eliminated.
9. In order to simulate car collisions with greater momentum the eggs will be dropped from successively greater heights (1.0 m, 1.5 m, 2.0 m, 2.5 m)
10. Devices must be completed within the time limit of 20 minutes.



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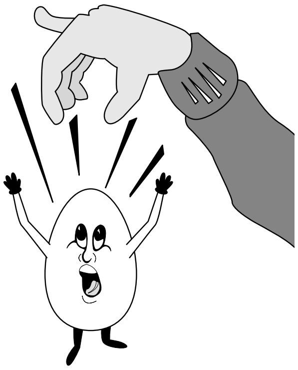
STUDENT ACTIVITY 3



Egg Crash! Designing a Collision Safety Device

Analysis

1. Draw a large diagram of your Collision Safety Device in the space below.

2. Describe your team's Collision Safety Device, the reasoning behind your design, and its performance during the various collisions. Refer to your diagram.

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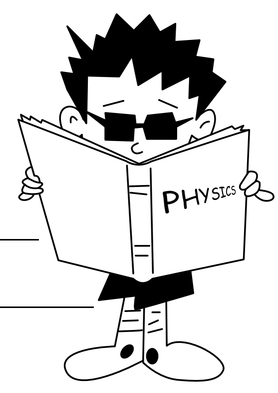
Crash questions

1. Explain how your Collision Safety Device is similar to an airbag in preventing injuries. Use the terms momentum impulse, impact force, and impact time in your response.



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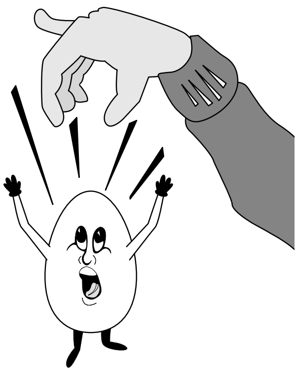
"CRASH COURSE" ACTIVITY

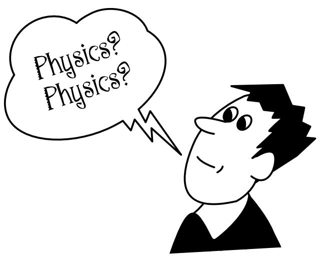


Egg Crash! Designing a Collision Safety Device

STUDENT ACTIVITY 3

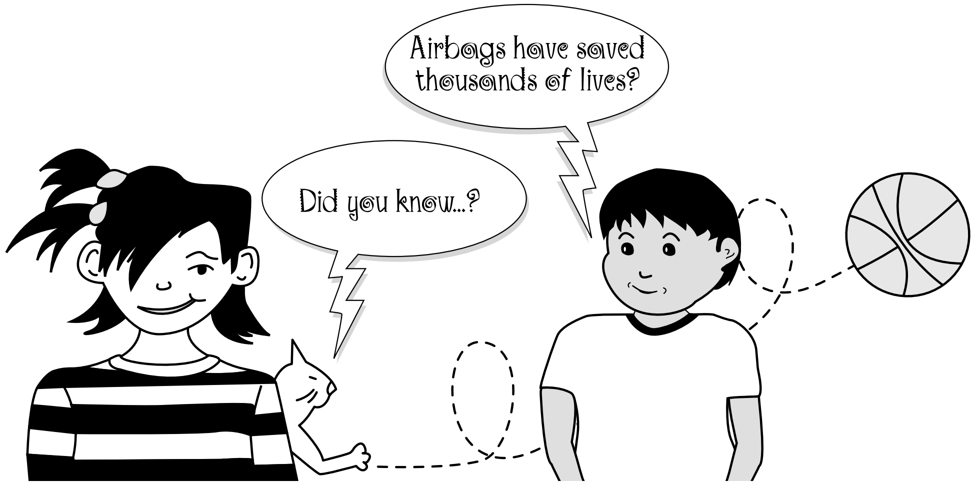
More crash questions

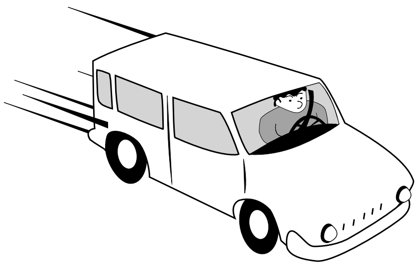
2. Compare the impulses, impact forces, and impact times of the following: Race Car #1 crashes to a stop by hitting a wall head on; Race Car #2 crashes to a stop by skidding a great distance along a wall.



3. List other vehicle safety devices that reduce the impact force by increasing the time of impact.

4. Explain why airbags are **not** alternatives to seat belts but are intended to be used with seat belts to increase safety.





"CRASH COURSE" ACTIVITY

Conservation: It's the Law!

TEACHER LESSON 4

Crash Course Definitions

energy: the ability to do work; "the stuff" that makes things move

work: the ability to apply a force (push or pull) over a distance, W = F x d

vector quantity: a quantity in physics, such as force, that has both magnitude and direction

scalar quantity: a quantity in physics, such as mass, that can be completely specified by its magnitude; it has no direction

Key question(s)

- Are bigger, more massive cars safer?
- Where does the energy "go" during a collision?

Grade levels: 9–12
Time required: 30–40 minutes

Objectives

Students will:

- describe a collision in terms of momentum and energy
- predict the relationship between energy and velocity of colliding objects
- infer how the law of conservation of momentum is applied in collisions
- infer how the law of conservation of energy is applied in collisions

National Science Education Standards

Standard A: Science as Inquiry

- Identify questions and concepts that guide scientific investigations
- Design and conduct scientific investigations

Standard B: Physical Science

- Motion and forces
- Conservation of energy

Standard E: Science and Technology

- Understanding about science and technology

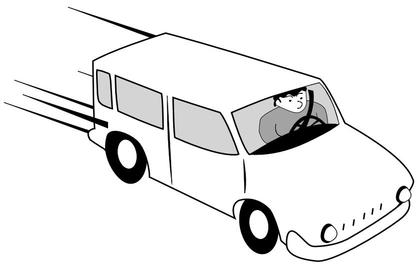
Standard F: Science in Personal and Social Perspectives

- Natural and human-induced hazards

Background information

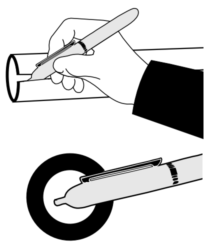
Car collisions can illustrate and help students discover the concept of energy. Energy is defined as the ability to do work. And work is the ability to apply a force (push or pull) over a distance.

All energy can be considered either kinetic energy, which is the energy of motion; potential energy, which is stored energy due to its relative position or condition; or energy contained by a field, such as light or radio waves. Underlying every car crash are two conservation laws of physics: the law of conservation of energy and the law of conservation of momentum. The conservation of energy law states that energy cannot be created or destroyed; it may be transformed from one form to another, but the total amount of energy never changes. The conservation of momentum law states that the total quantity of momentum of a group of objects does not change unless acted on by an outside force.



Conservation: It's the Law!

Like energy, momentum can transfer from one object to another. **Newton's Third Law of Motion** describes how all forces occur in equal pairs but in opposing directions. Consider a marble rolling along a track and hitting a motionless but identical marble. Upon colliding each marble experiences the same force but in opposite directions. The force of the first ball transfers to the second. Along with a transfer of forces is a transfer of momentum. Since both balls experience the same amount of force at the same time, the transfer is equal. What one marble loses in momentum the other ball gains (and the system's total momentum is unchanged). This observable phenomenon of maintaining and transferring momentum equally is called the **law of conservation of momentum.**

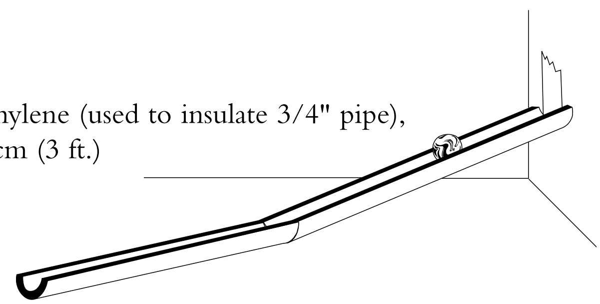


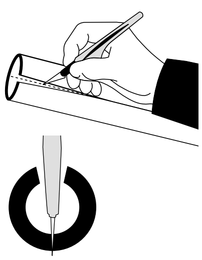
Momentum is a vector quantity, which means the direction it is traveling is also important. Vector quantities can cancel out if they are of the same magnitude but in opposite directions! Energy is not a vector quantity, it cannot be canceled, it must go somewhere! In a crash of a well-designed car, crash energy does the work that crushes the car's crumple zones. Some of the energy also becomes heat and sound generated by the crash.

Materials needed

For each group of two students:

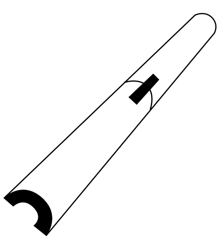
- 7 marbles, same size
- pipe insulation, 3/8" tubular polyethylene (used to insulate 3/4" pipe), without adhesive, cut length to 92 cm (3 ft.)
- masking tape, 30 cm
- meter stick
- books to support track (3–5)





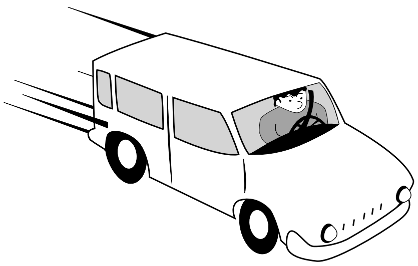
Getting ready

Pipe insulation can be purchased from large home supply stores for less than one dollar a section. The pipe insulation must be split down the middle and cut to create two open-faced, 6-foot rollways. Cut the rollways into 92cm (3 ft) length sections.



Procedure

1. Inform students that they are going to investigate the relationship between forces, motion, and energy. Divide students into pairs and distribute the supplies and student activity sheets, "Conservation: It's the Law!"
2. Have students set up the track as described and pictured on the Student Activity sheet. Tell students to test the track for a straight alignment by rolling a marble along the entire length of the track. If necessary, have students straighten and retape the track.
3. Briefly review the data tables and the procedure for completing the activity sheet.
4. Have students discover the relationships as you guide the lesson. Conduct a whole-class discussion addressing the Analysis and Crash Questions.



“CRASH COURSE” ACTIVITY

Conservation: It’s the Law!

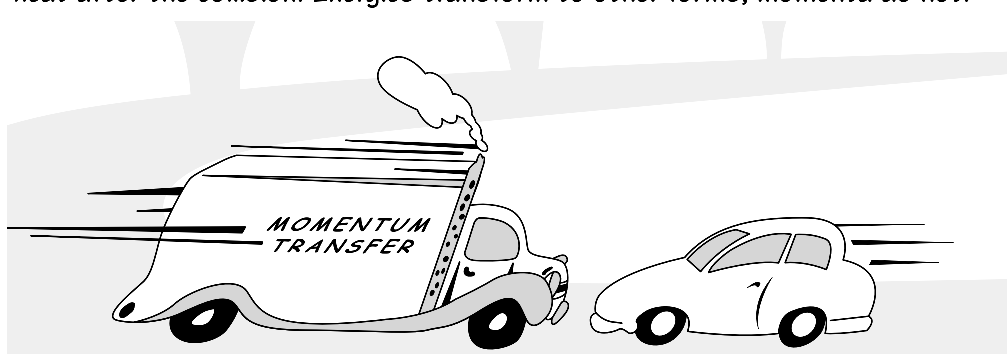
TEACHER LESSON 4

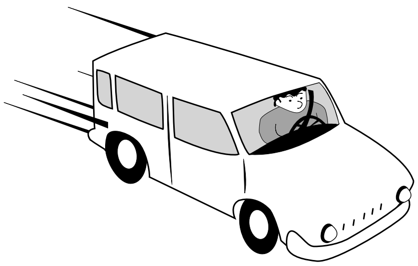
Answers to analysis questions:

1. Describe your results from Data Table #1.
   For all release heights, the number of released marbles equals the number of marbles knocked away from the row.
2. Describe your results from Data Table #2.
   The greater the release height, the greater the marble’s speed before the collision. The speed of the released marble(s) before impact equals the speed of the marble(s) knocked away.
3. How does the height of release affect the marbles’ energy and momentum?
   The greater the release height, the greater the marble’s potential energy. When released, its potential energy transforms to kinetic energy. The greater the kinetic energy, the greater the marble’s velocity and momentum. Momentum is the product of mass and velocity, p = mv.
4. What conclusions can you make from Data Table #1 regarding the energy of the released marble(s) and the energy of the marble(s) knocked away from the row?
   The energy before the collision equals the energy after the collision.
5. What conclusions can you make from Data Table #2 regarding the momentum of the released marble(s) and the momentum of the marble(s) knocked away from the row?
   The momentum before the collision equals the momentum after the collision.

Answers to crash questions

1. Describe the collision pictured below in terms of momentum, if the truck has four times the momentum of the car before the collision.
   With more momentum, the truck will keep going in its original direction and snap the car into sudden reverse. There is an equal change in momentum, but in opposite directions. Each experiences the same change in momentum but with differing effects due to their initial momenta. The truck had more momentum initially so the change is less noticeable; it continues in the same direction but at a reduced speed. The total momentum of both vehicles before the collision is equal to the total momentum after the collision.
2. Describe the collision pictured below in terms of energy, if the truck has four times the energy of the car before the collision.
   Unlike momentum, kinetic energy is a non-vector or scalar quantity and cannot be canceled. The energies add up, resulting in over four times the deformation and heat after the collision. Energies transform to other forms; momenta do not.





Conservation: It's the Law!

TEACHER LESSON 4

Additional crash questions

1. Use the following questions to further assess the students' conceptual knowledge.
   - What is the physics term used to describe how difficult it is to stop a moving object? **(Inertia in motion or momentum, calculated by mass x velocity = momentum; see "Activity #2: Momentum Bashing")**
   - How about head-on collisions with cars of the same speed but different masses? Let's say your heavy car is hit by a lighter car. What happens to your car?
     Your car is more massive therefore it has more momentum than the lighter car. When the cars collide, your heavier car would keep going in its original direction.
   - Now, what if your car is hit by a heavier car?
     The heavier car would drive your car backward during the crash. For example, if both cars were traveling at 30 mph and the heavier car had twice the mass of your car, then the passenger compartment of your lighter car would be decelerated from 30 mph to 0 mph and then accelerated backward to 10 mph. The speed change would be 40 mph for the lighter car, but the heavier car would experience a speed change of only 20 mph. Your lighter car causes you to experience greater changes in speed which result in greater forces applied to your car. Ouch!

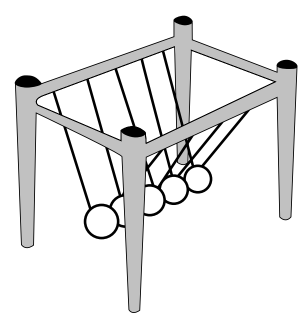
True or False. A heavy car and a light car collide head on. The force of impact is greater on the lighter car.
(False. The force between them is the same.)

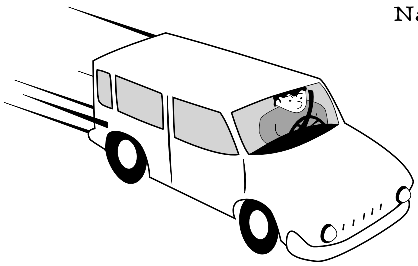
Apply **Newton's Third Law**—for every action there is an equal and opposite reaction. So the forces between two crashing cars are equal in opposite directions. Now, apply **Newton's Second Law, a = F/m**. Each car experiences the same force during the collision but the acceleration, or deceleration in this case, is much greater for the less massive car. Use the formula to help guide your thinking:

big car	**small car**
$F \div \mathbf{M} = a$	$F \div m = \mathbf{A}$

Extension

Have students explore a swinging-balls apparatus. Challenge them to answer this question: **When two balls are released and collide with the remaining row of balls, why doesn't one ball emerge with twice the speed at the other end?** (Momentum would be conserved but not energy. For energy to be conserved, **Kinetic energy** $(KE)_{in}$ must equal $(KE)_{out}$.)





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STUDENT ACTIVITY 4

Conservation: It's the Law!

Crash test question(s)

- Are bigger, more massive cars safer?
- Where does the energy "go" during a collision?

Purpose

- To describe a collision in terms of momentum and energy
- To infer how the law of conservation of momentum is applied in collisions
- To infer how the law of conservation of energy is applied in collisions

Materials needed for groups of two students:

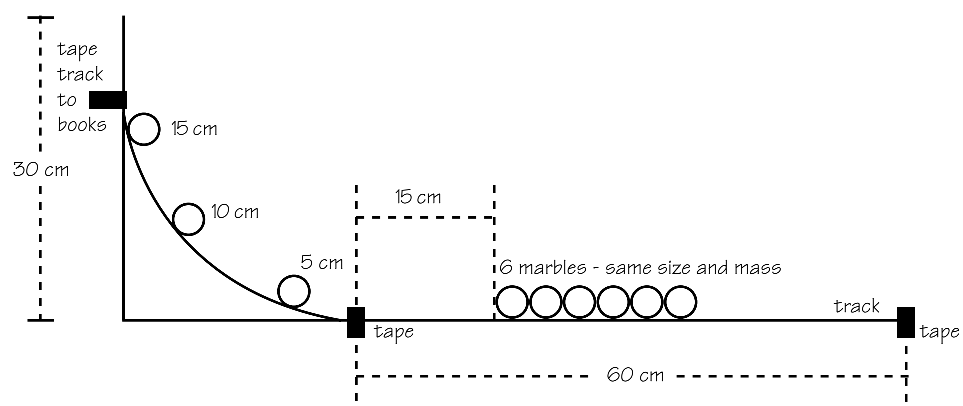
- pipe insulation track, 92 cm (3 ft.)
- 7 marbles, same size and mass
- masking tape, 30 cm
- meter stick
- books to support track (3–5)

Discussion

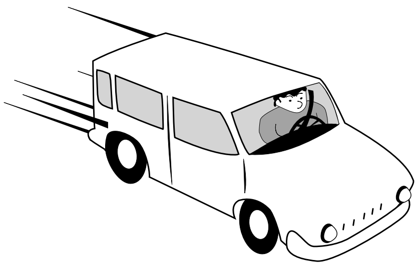
In the previous "Crash Course" activities, you have been studying how engineers use Newton's Laws and the concepts of momentum and impulse to study the physics of car crashes. Engineers at the Vehicle Research Center also rely on two laws that have been called the most powerful tools of mechanics (pun intended!), the conservation laws of energy and momentum. Let's explore the Laws!

Procedure

1. Using books as a support, tape one end of the track to a height of 25–30 cm. Using two more pieces of tape, create a flat, straight 60 cm rollway.



2. Using small pieces of tape and a ruler, measure and mark the following heights on the upward curve of the track: 5.0 cm, 10.0 cm, 15.0 cm (measured straight up from the surface of the desk, not along the curve of the track).



Conservation: It's the Law!

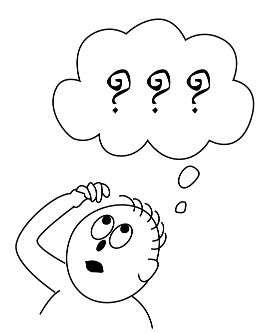
3. Place six marbles in the groove of the track. Allow about 15 cm between the end of the slope and the first marble in the line of six.
4. Push the marbles together so they all touch.
5. Place the last or seventh marble at the 5.0 cm mark on the upward slope.
6. Release the marble and allow it to roll down the track and collide with the row of marbles. Observe what happens! How many marbles roll away from the row? Record your observations in Data Table #1.
7. Place the marbles back in a row, making sure they all touch.
8. Repeat Step 6 from 10.0 cm and 15.0 cm using one marble.
9. Repeat Steps 6 and 7, with two, three, and four marbles.
10. Record results in Data Table #1.

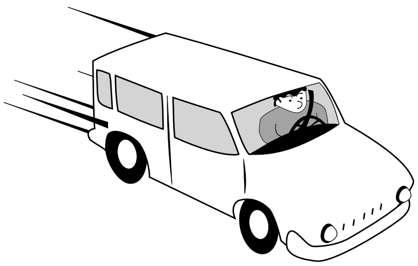
Data Table 1

Number of marbles released	Height of release	Number of marbles knocked away from the row
1	5.0 cm	
	10.0 cm	
	15.0 cm	
2	5.0 cm	
	10.0 cm	
	15.0 cm	
3	5.0 cm	
	10.0 cm	
	15.0 cm	
4	5.0 cm	
	10.0 cm	
	15.0 cm	

Data Table 2

Height of release	Number of marbles released	Speed of released marble(s) before impact (slow, medium, fast)	Speed of released marble(s) knocked away (slow, medium, fast)
5 cm	1		
	2		
	3		
10 cm	1		
	2		
	3		
15cm	1		
	2		
	3		
20 cm	1		
	2		
	3		





Conservation: It's the Law!

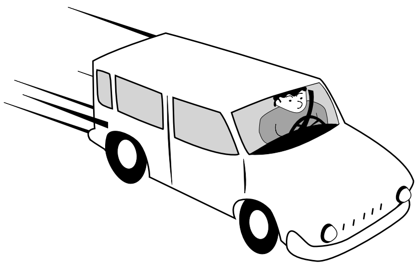
11. Next, place the marbles back in a row, again making sure they all touch.
12. Place one marble on the 5.0 cm mark and release it.
13. Try and compare the speed of the released marble just before it collides with the row to the speed of the marble knocked away from the row (qualitative speed descriptions: slow, medium, fast.)
14. Repeat Step 13 at 10.0 cm and 15.0 cm with one marble.
15. Repeat Steps 6 & 7, with two and three marbles.
16. Record your observations in Data Table #2.

Analysis

1. Describe your results from Data Table #1.

2. Describe your results from Data Table #2.

3. Reviewing Data Table #1, how does the number of marbles and their release height affect the marbles' energy and momentum?



Conservation: It's the Law!

STUDENT ACTIVITY 4

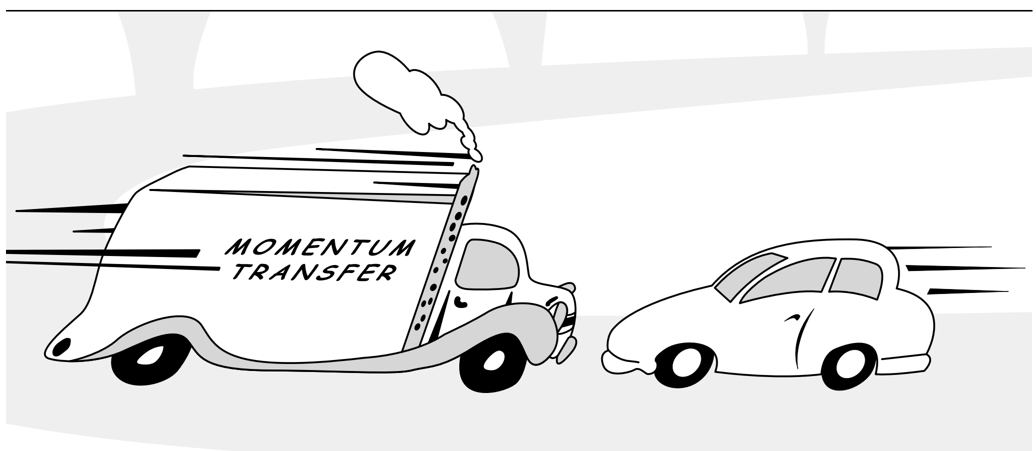
4. What conclusions can you make from Data Table #1 regarding the total energy of the released marble(s) and the total energy of the marble(s) knocked away from the row?

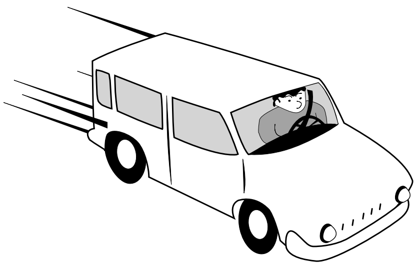
5. What conclusions can you make from Data Table #2 regarding the momentum of the released marble(s) just before impact and the momentum of the marble(s) knocked away from the row?

Crash questions

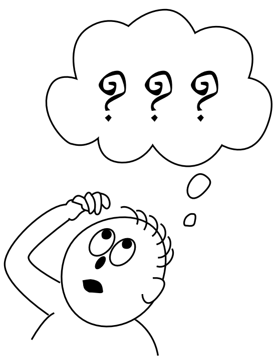
1. Describe the collision pictured below in terms of momentum, if the truck has four times the momentum of the car before the collision.

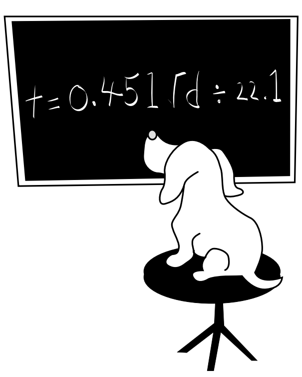
2. Describe the collision pictured below in terms of energy, if the truck has four times the energy of the car before the collision.

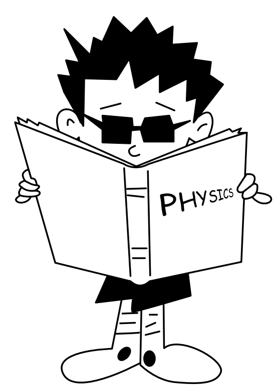




Conservation: It's the Law!







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