

Chapter 5

Momentum and Energy

Momentum

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Order is small momentum to large momentum.

Table A

Object	Amount of Momentum (describe in your own words)	Comments
Statue	It has mass, but no velocity, momentum is 0.	
Building	It has mass, but no velocity, momentum is 0.	This has a larger mass than a statue, but momentum is still 0.
Football	It has a larger velocity, but little mass.	
Slapshot	The puck has mass and a larger velocity than the football.	The puck is moving faster than the football.
Marathon runner	It has both mass and velocity.	The velocity is smallest of sprinter, runner, and skateboarder.
Skateboarder	It has about the same mass as runner, but has a larger velocity.	
Sprinter	It has same mass as runner and skateboarder, but travels with a larger velocity.	
Transit bus	It has a large mass and small velocity.	
NASCAR stock car	It has a smaller mass than the bus, but a much larger velocity.	The car is moving much faster than the bus. This makes up for the smaller mass of the car.

Math Connection

The velocities used are realistic velocities.

Table B

Object	Mass (kg)	Velocity (km/h)	Momentum (kg-km/h)	Comments
Transit bus	8 000	50	400 000	
Football (thrown)	0.5	35	17.5	
Sprinter	75	35	2700	
Golden Boy statue	1 650	0	0	
NASCAR stock car	1 545	300	463 500	
Marathon runner	65	12	780	
Slapshot	0.15	150	22.5	
Building	1 000 000	0	0	
Skateboarder	68	20	1360	

The ranking of the smallest to largest momentum is:

- Statue
- Building
- Football
- Puck (slapshot)
- Marathon runner
- Skateboarder
- Sprinter
- Transit bus
- NASCAR stock car

Impulse and Momentum

Note to Teacher:

Impulse and momentum can be related through Newton's Second Law.

In symbolic form, the equation for Newton's Second Law is: $\vec{F}_{\text{net}} = m\vec{a}$

Where:

\vec{F} is the unbalanced force.

m is the mass of the object.

\vec{a} is the acceleration of the object.

Acceleration is found using the equation:

$$\vec{a}_{\text{avg}} = \frac{D\vec{v}}{Dt}$$

If we substitute for \vec{a} in Newton's Second Law, it becomes:

$$\vec{F} = m \cdot \frac{D\vec{v}}{Dt}$$

Cross-multiply with Dt and:

$$\vec{F}Dt = mD\vec{v}$$

The $\vec{F} Dt$ part is called *impulse*. It can be thought of as the **cause** of motion changes.

$$\text{Impulse} = \vec{F}Dt \quad \text{Units: N} \cdot \text{s}$$

The $m D\vec{v}$ is **change in momentum** not just momentum.

This is the **effect** or change in motion caused by applying an impulse to the object. If an impulse is applied, an object undergoes a change in velocity and, hence, a change in momentum.

Change in momentum = $m D\vec{v}$ (has units of kg-m/s)

Both quantities are **vectors**.

DEMONSTRATION:

A piece of paper is placed under a beaker at the edge of a table. The paper is quickly pulled out from under the beaker. The beaker does not move. Here, the force of friction between the beaker and the paper acts for a short time. The impulse applied and, hence, the change in momentum of the beaker, are small.

If the paper is pulled gently along the table, the beaker will move with the paper, acquiring a large velocity. Here, the same force of friction acts, but over a long time, allowing the beaker to acquire a large velocity.

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1. **a.** large force—short time
 - hitting a baseball with a bat, hitting a golf ball
 - two cars crashing together
 - b.** small force for a long time
 - coasting to a stop while riding a bicycle
 - a sliding curling rock coming to a stop
 - c.** large force for a long time
 - a train speeding up or slowing down
 - a large boat or ship speeding up or slowing down
 - d.** small force over a short time
 - moving a pen or pencil while writing
2. **a.** Driving the golf ball

The large impulse can be obtained by swinging harder to increase the force, or using proper technique to increase the time of contact (i.e., follow-through). Both provide a large momentum to the ball.

Putting the golf ball

The small impulse can be obtained by exerting a small force with the putter on the ball. This decreases the momentum change the ball undergoes. Again, following through is important to maintain the correct direction.

**b.** Gymnast and reverse somersault

Before the dismount, the gymnast swings around the bar. As she falls, the force of gravity applies an impulse to her, increasing her speed and momentum, especially in the legs. The gymnast rises upwards on the other side. Once her hands release from the bar, the momentum is in the gymnast's body as she flies through the air.

c. Volleyball players “set up” a spike shot

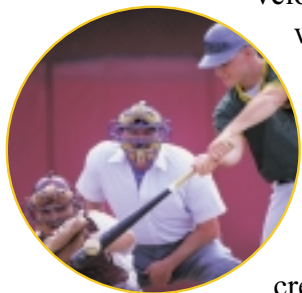
The setter must apply a force to the ball for a given length of time. If the setter can lengthen the time of contact with the ball, the force that must be applied to the ball can be reduced. This also allows for more control. The ball will have a momentum that will carry it in the correct direction and to the correct spot to be spiked. Good setters have “soft” hands. They can cushion the ball while it is in their hands and guide it with the right force in the right direction.

**d. Baseball players hitting a grand slam**

The player must swing the bat with a large force. This accelerates the bat to a high velocity. This requires strength on the batter’s part. Baseball players are seen warming up with weights on the bat. This strengthens the muscles needed to exert a large force on the bat and makes the bat feel very light once the rings are removed.

During the swing, the batter follows through, which lengthens the time of contact between the bat and the ball.

Both the large force and longer contact time increase the impulse applied and create a larger change in momentum. The ball is propelled with a larger velocity and travels farther, right out of the park.

**e. Car brakes for a yellow light**

The car must slow down and stop, decreasing its momentum to zero.

The braking force acting on the wheels can be small if the time to stop is large. This is the preferred method of stopping.

If the braking time must be small, then large braking forces are needed. The stop will be very abrupt and passengers and objects in the car will continue to move forward.

Drivers should “drive ahead.” As they approach an intersection, check the “Walk/Don’t walk” pedestrian signs. If the “Don’t walk” sign has been on for a long time, the green light is “stale” and the driver should be prepared to stop.

f. A catcher catches a fastball

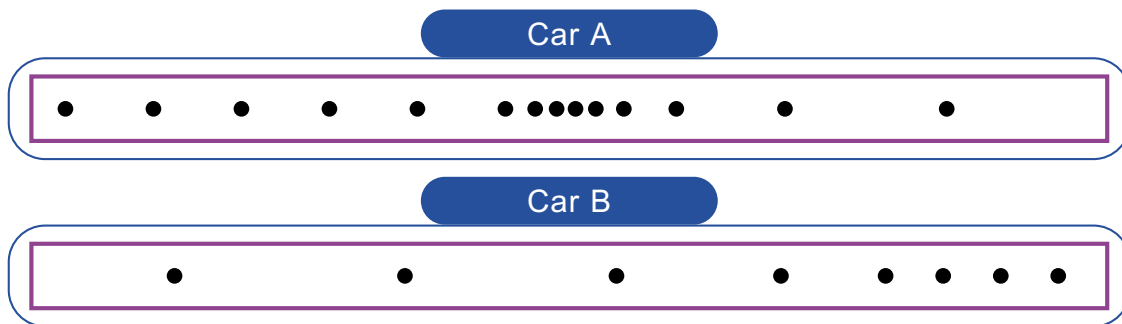
The ball must undergo a change in momentum to bring it to zero. The catcher would attempt to catch the ball in the webbing of the catcher’s mitt.

If the ball is caught flush on the palm of the hand, the ball stops in a very short time. To achieve the necessary change in momentum, a large force to stop the ball is required. The reaction force of the ball on the hand can damage the catcher’s hand.

If the ball is caught in the webbing, the length of time to stop the ball is increased, in turn decreasing the stopping force on the ball. Damage to the catcher’s hand is avoided.

The catcher can also lengthen the time of the catch by allowing her glove to move in the direction of motion of the ball as the catch is being made. This also decreases the stopping force and reduces the chances of injury to the catcher’s hand.

3. a. Car A experiences an impulse after six dots.
Car B experiences an impulse after one dot.



- b. Car A slowed to $1/3$ of its original velocity.
The change in momentum is a loss of $2/3$ of the original velocity.
Car B slowed to $1/4$ of its original velocity.
The change in momentum is a loss of $3/4$ of the original velocity.
Car B experiences the larger momentum change.
- c. Since Car B experienced the larger momentum change, it experienced the greater impulse.
- d. Car A experiences two impulses: one between six dots to seven dots; and after 10 dots, between 10 and 14 dots.

4. Mass halfback = 60 kg

Velocity of halfback = +3.2 m/s

Momentum of halfback = $m\vec{v} = 60 \text{ kg} * 3.2 \text{ m/s} = +192 \text{ kg}\cdot\text{m/s}$

Mass of lineman = 120 kg

Velocity of lineman = -1.8 m/s

Momentum of lineman = $m\vec{v} = -216 \text{ kg}\cdot\text{m/s}$

Since the lineman has the larger momentum, he will push the halfback backwards.

5. If the boulder and the boy have the same momentum, and we assume the boulder has a larger mass, the boy is currently running faster than the boulder is rolling down the hill. We can assume the boy cannot run any faster. However, the force of gravity will apply an impulse to the boulder. As time goes on, the boulder will gain momentum and roll more quickly. The boulder will roll faster than the boy can run and catch up to him. Eventually, the boy could be crushed.

or

The boy could simply step to the side, out of the boulder's path.

6. The person can throw the gold brick in one direction (e.g., east). This action force causes a reaction force of the brick on the fool pointing west.

So the fool applies an impulse to the brick in the easterly direction and the brick applies an impulse on the fool in the westerly direction.

The impulse applied to the fool appears as a change in momentum of the fool.

The fool slides across the ice to the shore with constant velocity, as there are no unbalanced forces acting on him.

He is not a fool. What good is gold when you are dead?

7. A spacecraft has a rocket, which is basically a chamber where fuel and oxygen are mixed and burn, producing heat and waste gases. The waste gases are forced out of a small opening at one end of the chamber. This rocket is at the side of the spacecraft.

The chamber walls exert a force (action force) on the gases, pushing them out the opening. The force of the chamber walls on the gases over a time interval gives an impulse to the gases.

By Newton's Third Law, the gases exert a reaction force on the chamber walls for the same length of time. This applies an impulse to the chamber walls, which are attached to the rocket. The rocket experiences a change in momentum. In this case, the resulting velocity change is due to the change in the direction of the velocity.

Challenge

Students may suggest cushioning devices, such as pillows, padded chairs/sofas, bubble wrap.

**Try
IT!**

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Be sure to try this activity. Students will be very impressed.

The principle behind it is to have the egg undergo its change in momentum over a long period of time. This reduces the stopping force required.

This is a natural lead-in to start discussing how passengers in vehicles can be protected when they must suddenly come to a stop (i.e., undergo a large momentum change).



Cushioning Devices

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Fifty years ago, cars were built with very strong, rigid bumpers. In car crashes, the rigid bumpers would stop the car quickly, as they would not collapse. This caused passengers in the vehicle to be stopped with a large stopping force, causing injuries to the passengers.



Over the years, cars were redesigned to have shock-absorbing bumpers. In collisions at low speeds, the shock absorbers would collapse, lengthening the stopping time and distance, and reducing the damage to vehicles and the injuries to passengers.

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1. Research Projects—Safety Devices
2. Design a car using modern safety features

The car should include a system to fasten the passengers in the car to prevent second collisions. This should include a shoulder harness/lap belt seat system. This keeps the passenger in place, including preventing the upper body from striking the steering wheel or dashboard. This also prevents a passenger from being thrown from the car and being injured by a second collision with the ground or some other object.

Objects inside the car, like the dashboard, should be padded so that body parts striking the padded surface will stop over a longer time and distance, reducing the stopping force. Objects like door handles should be recessed into the door. Knobs on the dashboard should be recessed and as flat as possible with a large radius so that the force of impact is spread out over a large area should a body part collide with the knob.

The car should include proper support of the back and head in case of a rear-end collision. The headrest should be high enough to be positioned properly behind the head.

The car should have crumple zones in the front and the rear of the car. In a collision, the crumple zones allow the car to stop over a longer period of time and a longer distance, decreasing the stopping force.

The car should have an impact-absorbing bumper. The bumper could be plastic, in which case it crumples during a collision. The bumper could also be attached to a shock absorber, which compresses and absorbs some of the energy of a collision.

The passenger compartment of the car should be strong enough not to flatten during a rollover. The cage of the car should remain intact, preventing the passengers from being crushed.

The passenger car should have air bags in the steering wheel and dashboard to cushion passengers as they continue to move forward when a car is stopped in a head-on collision. The air bags should be designed so that they do not injure the passengers. Injuries can result from the rapidly expanding air bag striking a passenger. The air bags should be designed to accommodate passengers of all sizes. Cars can also have side air bags built into the doors to cushion the passenger during side collisions.

Since children are often the passengers in a car, provisions for a child safety seat should be built into the seating in the car.

Windows should be laminated. This will prevent the glass from breaking up into shards that could then act as knives to cut the passengers. Laminating the glass (i.e., putting two layers of glass held together by a layer of adhesive) allows the glass to break into tiny pieces that are held in place by the adhesive. The windshield must be strong enough to prevent the passenger's head from poking through the windshield. If this happens, the hole in the glass closes and, as the passenger's momentum is reversed, the passenger could be decapitated.

3. Investigate NASCAR Regulations Online

Seat Belts:

<<http://www.evergreenspeedway.com/03brules.htm>>

<<http://www.speedbowl.com/speedpages/2002GeneralRules.html>>

<<http://www.phy6.org/stargaze/Sfall.htm>>

Roll Bar:

<http://www.google.ca/search?q=cache:r6H7FGQPDp4C:www.iceracingthunderbay.com/images/Rules_Regulations.pdf+NASCAR+safety+regulations+rollover+cages&hl=en&ie=UTF-8>

<<http://cc4w.org/favorite.htm>>

<<http://www.evergreenspeedway.com/03brules.htm>>

<<http://www.stockton99speedway.com/Division%20rules/WLM2003Rules.html>>

Head Restraints—HANS (Head and Neck Support):

<<http://auto.howstuffworks.com/nascar-safety4.htm>>

<<http://drive.fairfax.com.au/content/20000412/motorsport/motor3.html>>

<http://www.usatoday.com/sports/motor/nascar/2002-12-12-hans-side_x.htm>

Head Restraints—Hutchens Device:

<<http://www.stockcarproducts.com/safety9.htm>>

<<http://www.mascosafety.com/hutchens.html>>

Crumple Zones:

<<http://www.tennessean.com/sii/00/07/08/safety08.shtml>>

A good general information source on NASCAR safety.

<<http://www.autoracing1.com/MarkC/2001/0226CrumpleZones.htm>>

One Stop Site: This site provides links to a variety of physics sites dealing with “Moving About.”

<<http://www.phy.ntnu.edu.tw/java/carDistance/carAccident.html>>

4. Crumple Zone

The packaging of objects, such as TVs, computer monitors, et cetera, includes rigid foam to keep the object in place in the centre of a box. There is a space between the object and the box so that the box can crumple to absorb some of the energy in a collision without damaging the contents.

Padded Cushions:

Padded cushions spread out the force of contact between objects, lessening the force acting on one unit area. A smaller force results in less damage being done to the part of the body in that unit area. For example, padding in chairs, couches, and seats of all kinds function in this way. These are static situations where there is no motion.

For objects in motion, the same principle applies. Examples would be found in amusement-park rides. Here, the parts of the ride with which the riders come in contact, often violent contact, are padded. In the home, small children are constantly falling. Bumpers placed on corners and sharp edges can greatly reduce the injuries suffered by children. In industry, padded cushions are used where objects contact each other at low speed. For example, if a trailer is being backed into a loading dock, the padded cushion lengthens the stopping distance and prevents damage to the trailer and the dock.

Air Bags:

Hollywood stunt performers use large air bags to cushion their falls from a great height.

Air bags are used in packaging as bubble wrap.

Roll Bars:

Farm tractors use roll bars above the driver. Tractors tend to flip over backwards (i.e., the front end lifts up and swings up over the driver). The roll bar protects the driver from being crushed.

Tractors that are used on hillsides also use roll bars, as they may topple over on their sides.

Recreational vehicles, which are used in all sorts of uneven terrain, have roll bars to protect the driver.

Bumpers:

Bumpers are used on industrial equipment, such as moving platforms, conveyers, et cetera. The bumpers prevent damage to other equipment and to humans in case of collisions.

5. a. Dr. Claire Straith

He was a plastic surgeon. In the 1930s, he met many patients who were disfigured from car accidents. The disfigurements were caused by the second collision of the patient's face with the dashboard or the knobs on the dashboard in the car. Dr. Straith campaigned for the automobile makers to install padded dashboards and to redesign the knobs on the dashboard. Today, all cars have padded dashboards, and the knobs on the dashboard are recessed.

b. Bela Berenyi

He was an engineer at Mercedes during the 1950s. Until 1959, cars were built to be very strong. They could crash together without crumpling very much. The force of the collision was transmitted through the rigid car body to the passengers. The energy from the crash was dissipated as work was done on the passengers during second collisions, and this resulted in injuries.

Bela Berenyi designed a car body that would dissipate the force exerted on the passengers. The design includes two crumple zones: one at the front of the car and the other at the rear of the car, with a rigid passenger compartment. The crumple zones were designed to distort in a predictable way. The energy of the crash would go into the work done to crumple the crumple zones. During frontal collisions, the structure supporting the engine would slide under the passenger compartment rather than into it. Later, side-impact beams were placed in the side door to help absorb the force of a side collision. This completed the crumple zones on all sides of the car.

c. Nils Bohlin

He was an engineer who worked for Volvo. The first seat belts came out in 1949. These were two-point belts that were strapped across the hips. The hips were held in place by the belt during a crash, but the upper torso was not restrained. Drivers especially suffered injuries as the upper torso collided with the steering wheel. Passengers' upper torsos collided with the dashboard and windshield. Spinal injuries occurred as well.

The engineers at Volvo produced a two-point belt that went across the chest. However, in crashes, the hips, where the centre of gravity was found, would fly forward. The rest of the body would follow and the chin would be caught by the chest strap. This resulted in head and neck injuries and, sometimes, decapitation.

Nils Bohlin developed the three-point lap belt/shoulder harness style seat belt. This kept the hips in place and prevented the upper torso from striking the steering wheel, dashboard, or windshield. If properly adjusted, it also prevented the body from sliding under the belt.

d. John Hetrick

In 1952, John Hetrick was granted the patent for the mechanism that has evolved into the modern-day air bag. He noticed that compressed air could very quickly fill up a canvas bag. This is the basic design of an air bag. An air bag has a sensor that sends an electrical signal to an inflator mechanism when the air bag is needed. The inflator mechanism quickly inflates the air bag. The air bag cushions the passenger as he is stopped, spreading out the stopping force and lengthening the stopping time and distance. Once the passenger is stopped, the air bag deflates. This all occurs within about 0.5 seconds.

The advantage of the air bag is that it is user-independent. It works automatically when needed, unlike seat belts which must be done up by the driver and passengers. Around 1970, the National Highway Traffic Safety Administration (NHTSA) in the U.S. found that only 15 percent of people used seat belts. They put pressure on the automobile makers to develop the technology of the air bag. By 1980, Mercedes offered them. By 1988, the NHTSA forced all manufacturers to install them in their new models.

Problems arose where passengers were injured or killed from the force of the air bag as it was inflated. Children and small women who were improperly restrained also suffered injury and death. Late-model cars have two sensors. In low-speed collisions, one sensor fires and the air bag is inflated less and to a smaller size. This lessens the injuries to passengers. In high-speed collisions, both sensors fire and the air bag operates at full inflation and full size.

e. Ralph Nader

Ralph Nader is an American consumer activist fighting for the rights of the consumer against those corporations that build things as cheaply as possible so as to maximize profit.

In 1965, Nader wrote a book called *Unsafe at Any Speed: The Designed-in Dangers of the American Automobile* (Grossman). The book maintained that cars were built for style, cost, and performance, but not for passenger safety. He claimed that the Detroit automobile makers did not place a high priority on safety design in the cars they built. Senate hearings were held in the United States and the resulting publicity made the book a best-seller.

The upshot of all this was that the government of the United States formed the National Highway Traffic Safety Administration. This agency tells the automobile makers what to build into their cars to enhance passenger safety.

Protecting Occupants



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1. The package should have a crumple zone to lengthen stopping distance and time.

If the package does collapse, it must not do so to such an extent that the egg is damaged.

2. The egg can move inside the package. This will lengthen the stopping distance and stopping time, reducing the force.

The egg should not be allowed to move so freely within the package that it will contact the outer package.

3. Cushioning materials like polystyrene, cotton batting, plastic bubble wraps, and packing chips can be used to absorb the shock.

Some students have used straws inside the compartment. Others have used straws on the outside of the compartment.

4. Student responses will vary.

Momentum and Energy in a Collision

Note to Teacher: In Newton’s Cradle, the total momentum is conserved. If sphere 1 receives some momentum, this momentum is transferred to sphere 6 during the collision. Sphere 1 loses its momentum but sphere 6 gains an equal amount of momentum.

The total momentum in the system is conserved.

Check with the physics teacher in your school for one of these devices.

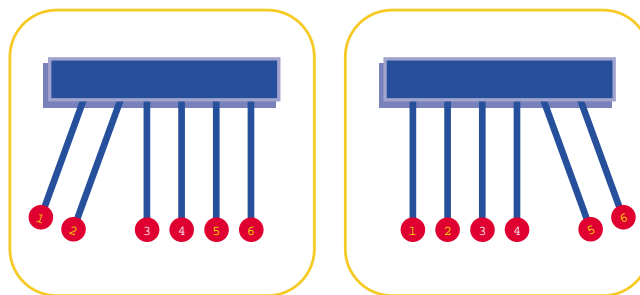
Again, Walter Fendt has an applet, appropriately named Newton’s Cradle, which will demonstrate how this device works.

<<http://www.walter-fendt.de/ph14e/ncradle.htm>>

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1. Pulling one sphere (sphere 1) and releasing it causes one sphere (sphere 6) to move away from the other end.
2. Pulling two spheres (spheres 1 and 2) away and releasing them causes two spheres (spheres 5 and 6) to move away from the other end.
3. Pulling three spheres (spheres 1, 2, and 3) away and releasing them causes three spheres (4, 5, and 6) to move away from the other end.
4. Pulling one sphere away from each end (spheres 1 and 6) and releasing them at the same time results in these two spheres striking the motionless spheres and rebounding with the same speed but in the opposite direction. The momentum of each sphere is reversed but the total momentum remains the same.



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1. If energy were not conserved but destroyed, the world would run out of energy.

Example: We eat food to supply chemical energy that our body uses to produce energy to keep us warm and to do work such as move other things and ourselves. If this energy was destroyed during conversion, the energy in the food could not be used to keep us warm or to move things.

If energy could be created, the world would be accumulating energy.

Example: A car could work with no fuel. The energy of motion would suddenly appear with no fuel as an energy source and no engine.

2. The kinetic energy that appears where a car accelerates originates in the chemical potential energy stored in the fuel (gasoline) and oxygen, which react during combustion. The combustion reaction releases this energy as heat. The gas molecules move more quickly and push down on the piston, creating kinetic energy. The piston turns the crankshaft in the engine to the transmission, which turns the wheels. The turning wheels exert a force on the road, pushing the car forward. The kinetic energy is transferred along from the piston to the crankshaft to the transmission to the wheels to the car as a whole.

PRACTICE—PAGE 53



1. Roller Coaster

At the top of the ride, the roller coaster has a great deal of potential energy. As the roller coaster falls, it loses potential energy but picks up kinetic energy. At the bottom of the ride, the roller coaster has little potential energy but a great deal of kinetic energy.

2. Bungee Jumper

At the top the jump there is a lot of potential energy due to gravity and no kinetic energy. As the jumper falls, she loses gravitational potential energy and gains kinetic energy.

When the bungee cord starts to stretch, some gravitational potential energy and kinetic energy are converted into elastic potential energy, stored in the cord.

At the bottom, all the original gravitational potential energy is converted into elastic potential energy. There is no kinetic energy.



3. Car Crash

As the car accelerates, chemical potential energy is converted into (heat) kinetic energy in the particles of the combustion products of gasoline and oxygen. The kinetic energy is transferred into kinetic energy of the pistons in the engine, which turn the crankshaft, giving it kinetic energy. The transmission transfers this kinetic energy to the wheels. The wheels push the car forward.

While traveling at a constant speed, the chemical potential energy from the fuel is used to overcome friction. This energy is lost to heat and sound.

When the car brakes, the kinetic energy is converted into other forms. Heat is produced by the brake shoes rubbing against the rotors. The tires skid on the road, producing heat. Sound is also produced.

When the car hits the side panel of the truck, more kinetic energy is lost by the car. Some of this kinetic energy is converted into sound. Most of the kinetic energy is lost as the metal bodies of the car and truck are bent out of shape. The metal heats up.



4. Pole Vaulter

A pole vaulter runs. He has kinetic energy.

When the vaulter plants the pole, the pole bends. The kinetic energy of the vaulter is converted into potential energy in the bent pole.

The pole straightens, lifting the vaulter. The pole loses elastic potential energy. The vaulter gains gravitational potential energy.

At the top, the vaulter has gravitational potential energy and a little kinetic energy.

As the vaulter falls, he loses gravitational potential energy and gains kinetic energy.

5. Pogo Stick

At the top of the jump, the child has little kinetic energy. There is no elastic potential energy in the pogo stick. The child has gravitational potential energy.

As the child falls, she gains some kinetic energy, and she loses gravitational potential energy. This energy is used to do work to compress the spring, becoming potential energy as well, coming to a stop at the bottom of the jump.

The spring loses its potential energy as it expands, doing work to raise the child, giving her gravitational potential energy, and to move the child upwards, giving her kinetic energy.

As the child continues to rise, lifting the pogo stick off the ground, the kinetic energy is converted into gravitational potential energy. The child arrives at the top with no kinetic energy.



6. Cars with Spring-Loaded Bumpers

As the cars collide, their kinetic energy is used to do work to compress the springs. The kinetic energy becomes elastic potential energy.

When the cars approach as close as possible, they stop. The original kinetic energy is now all stored in the springs as elastic potential energy.

As the springs expand, the elastic potential energy is converted back into kinetic energy in the cars.

When the cars no longer have the bumpers in contact, the kinetic energy of the cars should be equal to their starting kinetic energy.

The occupants of the cars, if they are fastened to the car, will experience the same transformations as the car.