Table of Contents

Chapter 3

Conservation Laws

Look around you. Do you see any changes taking place? Is a light bulb giving off heat and light? Is the sun shining? Are your eyes moving across the page while you read this introduction? When an object falls toward Earth, when you play a sport or a musical instrument, when your alarm clock wakes you up in the morning, and when a bird flies through the air, there are changes taking place that could not occur without the effects of *energy*.

Energy is everywhere! Energy is responsible for explaining "how the world works". As you read this chapter think about the examples and see if you can identify the forms of energy that are responsible for the changes that take place in each. Skateboarding, astronauts, car crashes, ball throwing, billiards, and tennis are just some of the physical systems you will encounter. Studying physics also requires energy, so always eat a good breakfast!

Key Questions

- ✓ Do objects at rest ever have any forces acting on them?
- ✓ Why does a faster skateboarder take more force to stop than a slower one with the same mass?
- ✓ How can energy be so important when it cannot be smelled, touched, tasted, seen, or heard?

Table of Contents

3.1 Newton's Third Law and Momentum

F*or every action there is an equal and opposite reaction*. This section is about the true meaning of this statement, known as Newton's third law of motion. In the last section, you learned that forces cause changes in motion. However, this does not mean that objects at rest experience no forces! What is that keeps your book perfectly still on the table as you read it even though you *know* gravity exerts a force on the book (Figure 3.1)? "Force" is a good answer to this question and the third law is the key to understanding why.

Vocabulary

Newton's third law, momentum, impulse, law of conservation of momentum

Objectives

- ✓ Use Newton's third law to explain various situations.
- ✓ Explain the relationship between Newton's third law and momentum conservation.
- ✓ Solve recoil problems.

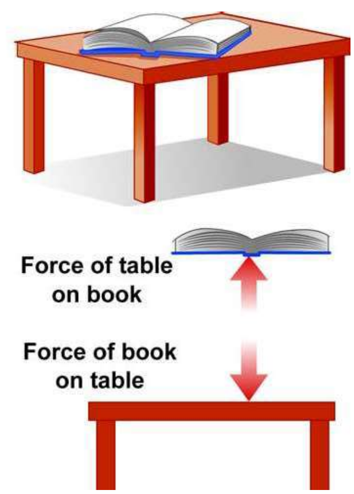
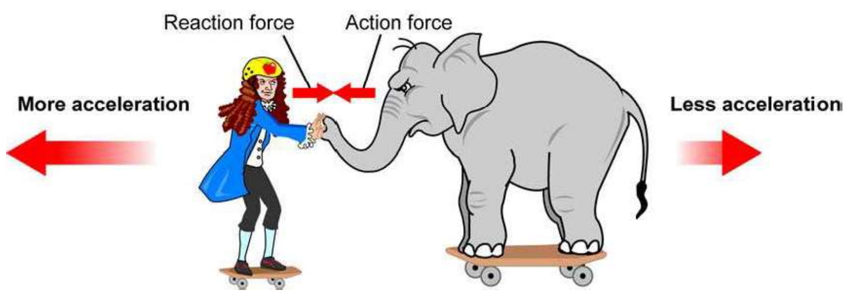


Figure 3.1: *There are forces acting even when things are not moving.*

Newton on a skateboard

An imaginary skateboard contest Imagine a skateboard contest between Newton and an elephant. They can only push against each other, not against the ground. The fastest one wins. The elephant knows it is much stronger and pushes off Newton with a huge force thinking it will surely win. But who does win?



The winner Newton wins — and will always win. No matter how hard the elephant pushes, Newton always moves away at a greater speed. In fact, Newton doesn't have to push at all and he still wins. Why?

Forces always come in pairs You already know it takes force to make both Newton and the elephant move. Newton wins because *forces always come in pairs*. The elephant pushes against Newton and that *action* force pushes Newton away. The elephant's force against Newton creates a *reaction* force against the elephant. Since the action and reaction forces are equal in strength and because of Newton's second law of motion ($a = F/m$), Newton accelerates more because his mass is smaller.

The third law of motion

The first and second laws

The first and second laws of motion apply to single objects. The first law says an object will remain at rest or in motion at constant velocity unless acted upon by a net force. The second law says the acceleration of an object is directly proportional to force and inversely proportional to the mass ($a = F/m$).

The third law operates with pairs of objects

In contrast to the first two laws, the third law of motion deals with pairs of objects. This is because *all forces come in pairs*. **Newton's third law** states that every action force creates a reaction force that is equal in strength and opposite in direction.

For every action force, there is a reaction force equal in strength and opposite in direction.

Forces *only* come in action-reaction pairs. There can never be a single force, alone, without its action-reaction partner. The force exerted by the elephant (action) moves Newton since it acts on Newton. The reaction force acting back on the elephant is what moves the elephant.

The labels "action" and "reaction"

The words action and reaction are just labels. It does not matter which force is called action and which is reaction. You choose one to call the action and then call the other one the reaction (Figure 3.2).

A skateboard example

Think carefully about moving the usual way on a skateboard. Your foot exerts a force backward against the ground. The force acts *on* the ground. However, *you* move, so a force must act on you. Why do you move? What force acts on you? You move because the action force of your foot against the ground creates a reaction force of the ground against your foot. You "feel" the ground because you sense the reaction force pressing on your foot. The reaction force is what makes you move because it acts on *you* (Figure 3.3).

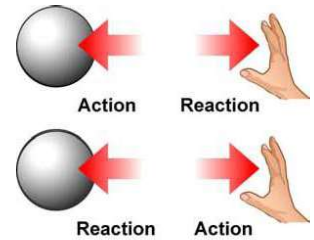


Figure 3.2: *It doesn't matter which force you call the action and which the reaction. The action and reaction forces are interchangeable.*

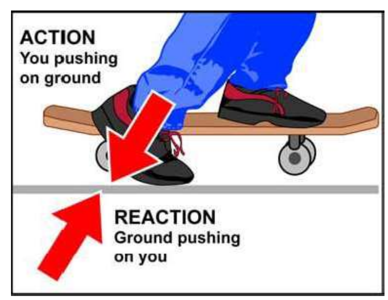


Figure 3.3: *All forces come in pairs. When you push on the ground (action), the reaction of the ground pushing back on your foot is what makes you move.*

Table of Contents

Action and reaction forces

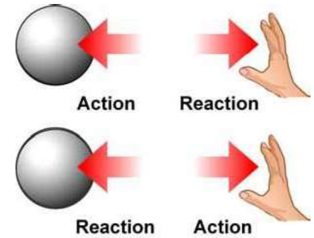


Figure 3.4: *An example diagram showing the action and reaction forces in throwing a ball.*

Action and reaction forces do not cancel It is easy to get confused thinking about action and reaction forces. Why don't they cancel each other out? The reason is that action and reaction forces act on different objects. For example, think about throwing a ball. When you throw a ball, you apply the action force to the ball, creating the ball's acceleration. The reaction is the ball pushing back against your hand. The action acts on the ball and the reaction acts on your hand. The forces do not cancel because they act on different objects. You can only cancel forces if they act on the same object (Figure 3.4).

Draw diagrams When sorting out action and reaction forces it is helpful to draw diagrams. Draw each object apart from the other. Represent each force as an arrow in the appropriate direction.

Identifying action and reaction Here are some guidelines to help you sort out action and reaction forces:

- Both are always there whenever any force appears.
- They always have the exact same strength.
- They always act in opposite directions.
- They always act on different objects.
- Both are real forces and either (or both) can cause acceleration.

Action and reaction

A woman with a weight of 500 N is sitting on a chair. Describe an action-reaction pair of forces.

1. Looking for: You are asked for a pair of action and reaction forces.

2. Given: You are given one force in newtons.

3. Relationships: Action-reaction forces are equal and opposite, and act on different objects.

4. Solution: The force of 500 N exerted by the woman on the chair seat is an action. The chair seat acting on the woman with an upward force of 500 N is a reaction.

Your turn...

a. A baseball player hits a ball with a bat. Describe an action-reaction pair of forces. **Answer:** The force of the bat on the ball accelerates the ball. The force of the ball on the bat (reaction) slows down the swinging bat (action).

b. Earth and its moon are linked by an action-reaction pair. **Answer:** Earth attracts the moon (action) and the moon attracts Earth (reaction) in an action-reaction pair. Both action and reaction are due to gravity.

Momentum

Faster objects are harder to stop

Imagine two kids on skateboards are moving toward you (Figure 3.5). Each has a mass of 40 kilograms. One is moving at one meter per second and the other at 10 meters per second. Which one is harder to stop?

You already learned that inertia comes from mass. That explains why an 80-kilogram skateboarder is harder to stop than a 40-kilogram skateboarder. But how do you account for the fact that a faster skateboarder takes more force to stop than a slower one with the *same* mass?

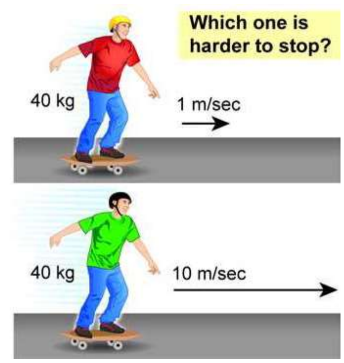


Figure 3.5: *Stopping a fast-moving object is harder than stopping a slow-moving on.*

Momentum

The answer is a new quantity called **momentum.** The momentum of a moving object is its mass multiplied by its velocity. Like inertia, momentum measures a moving object's resistance to changes in its motion. However, momentum includes the effects of speed and direction as well as mass. The symbol *p* is used to represent momentum.

MOMENTUM

$$p = mv$$

Momentum (kg·m/sec) → p; m ← *Mass* (kg); v ← *Velocity* (m/sec)

Units of momentum

The units of momentum are the units of mass multiplied by the units of velocity. When mass is in kilograms and velocity is in meters per second, momentum is in kilogram·meters per second (kg·m/sec).

Calculating momentum

Momentum is calculated with velocity instead of speed because the direction of momentum is always important. A common choice is to make positive momentum to the right and negative momentum to the left (Figure 3.6).

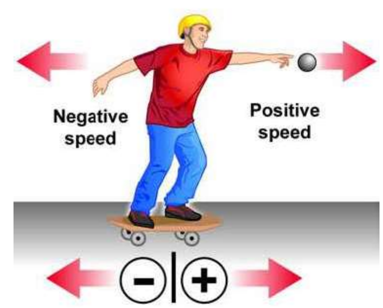


Figure 3.6: *The direction is important when calculating momentum. We use positive and negative numbers to represent opposite directions.*

Table of Contents

Impulse

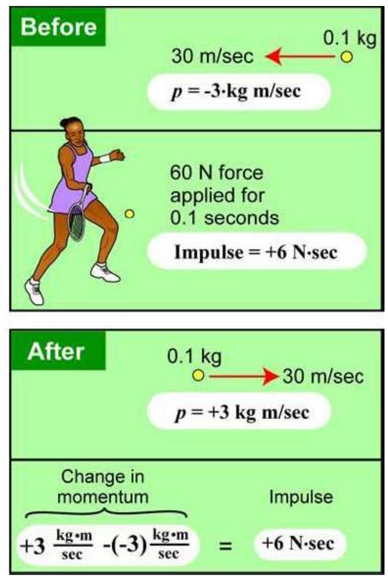
Force changes momentum Momentum changes when velocity changes. Since force is what changes velocity, that means that force is also linked to changes in momentum. The relationship with momentum gives us an important new way to look at force.

Impulse A change in an object's momentum depends on the net force and also on the amount of time the force is applied. The change in momentum is equal to the net force multiplied by the time the force acts. A change in momentum created by a force exerted over time is called **impulse**.

IMPULSE

$$Ft = mv_2 - mv_1$$

Impulse (N·sec *or* kg·m/sec); *Force* (N); *Time* (sec); *Mass* (kg); *Initial speed* (m/sec); *Final speed* (m/sec)



Units of impulse Notice that the force side of the equation has units of N·sec, while the momentum side has units of momentum, kg·m/sec. These are the same units, since 1 N is 1 kg·m/s^2. Impulse can be correctly expressed either way.

Force and momentum

A net force of 100 N is applied for 5 seconds to a 10-kg car that is initially at rest. What is the speed of the car at the end of the 5 seconds.

1. Looking for: You are asked for the speed.

2. Given: You are given the net force in newtons, the time the force acts in seconds, and the mass of the car in kilograms.

3. Relationships: impulse = force × time = change in momentum; momentum = mass × velocity.

4. Solution: The car's final momentum = 100 N × 5 seconds = 500 kg·m/sec.
Speed is momentum divided by mass, or v = (500 kg·m/sec) ÷ 10 kg = 50 m/sec

Your turn...

a. A 15-N force acts for 10 seconds on a 1-kg ball initially at rest. What is the ball's final momentum? **Answer:** 150 kg·m/sec

b. How much time should a 100-N force take to increase the speed of a 10-kg car from 10 m/sec to 100 m/sec? **Answer:** 9 sec

The law of momentum conservation

An important new law

We are now going to combine Newton's third law with the relationship between force and momentum. The result is a powerful new tool for understanding motion: the law of conservation of momentum. This law allows us to make accurate predictions about what happens before and after an interaction even if we don't know the details about the interaction itself.

Momentum in an action-reaction pair

When two objects exert forces on each other in an action-reaction pair, their motions are affected as a pair. If you stand on a skateboard and throw a bowling ball, you apply force to the ball. That force changes the momentum of the ball.

The third law says the ball exerts an equal and opposite force back on you. Therefore, *your* momentum also changes. Since the forces are exactly equal and opposite, the changes in momentum are also equal and opposite. If the ball gains +20 kg·m/sec of forward momentum, you must gain **-**20 kg·m/sec of backward momentum (Figure 3.7).

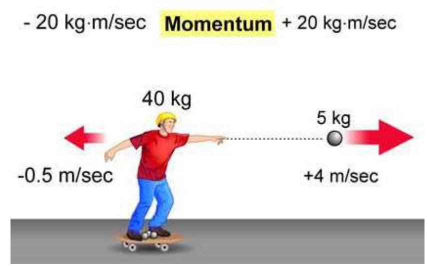


Figure 3.7: *The result of the skateboarder throwing a 1-kg ball at a speed of 20 m/sec is that he and the board, with a total mass of 40 kg, move backward at a speed of -0.5 m/sec, if you ignore friction.*

The law of conservation of momentum

Because of the third law, the total momentum of two interacting objects stays constant. If one gains momentum, the other loses the same amount, leaving the total unchanged. This is the **law of conservation of momentum**. The law says the total momentum in a system of interacting objects cannot change as long all forces act only between the objects in the system.

If interacting objects in a system are not acted on by outside forces, the total amount of momentum in the system cannot change.

Forces inside and outside the system

Forces outside the system, such as friction and gravity, can change the total momentum of the system. However, if ALL objects that exert forces are included in the system, the total momentum stays perfectly constant. When you jump up, the reaction force from the ground gives you upward momentum. The action force from your feet gives the *entire Earth* an equal amount of downward momentum and the universe keeps perfect balance. No one notices the planet move because it has so much more mass than you so its increase in momentum creates negligible velocity (Figure 3.8).

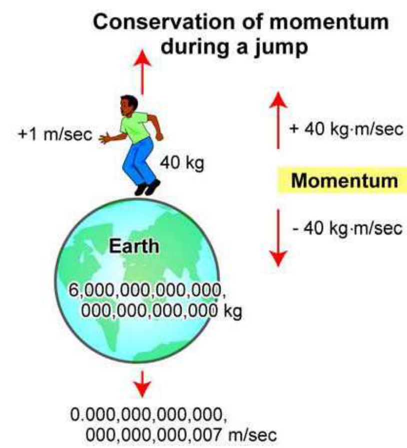
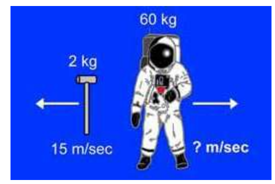


Figure 3.8: *When you jump, your body and Earth gain equal and opposite amounts of momentum.*

Table of Contents

Using the momentum relationship

An astronaut floating in space throws a 2-kilogram hammer to the left at 15 m/sec. If the astronaut's mass is 60 kilograms, how fast does the astronaut move to the right after throwing the hammer?



1. Looking for: You are asked for the speed of the astronaut after throwing the hammer.

2. Given: You are given the mass of the hammer in kilograms and the speed of the hammer in m/sec and the mass of the astronaut in kilograms.

3. Relationships: The total momentum before the hammer is thrown must be the same as the total after. Momentum = mass × velocity. A negative sign indicates the direction of motion is to the left.

4. Solution: Both the astronaut and hammer were initially at rest, so the initial momentum was zero. Use subscripts (*a* and *h*) to distinguish between the astronaut and the hammer.

$m_a v_a + m_h v_h = 0$

Plug in the known numbers:

$(60\text{ kg})(v_a) + (2\text{ kg})(-15\text{ m/sec}) = 0$

Solve:

$(60\text{ kg})(v_a) = +30\text{ kg·m/sec}$

$v_a = +0.5\text{ m/sec}$ The astronaut moves to the right at a speed of 0.5 m/sec.

Your turn...

a. Two children on ice skates start at rest and push off from each other. One has a mass of 30 kg and moves back at 2 m/sec. The other has a mass of 15 kg. What is the second child's speed? **Answer:** 4 m/sec

b. Standing on an icy pond, you throw a 0.5 kg ball at 40 m/sec. You move back at 0.4 m/sec. What is your mass? **Answer:** 50 kg

3.1 Section Review

1. List three action and reaction pairs shown in the picture at right.
2. Why don't action and reaction forces cancel?
3. Use impulse to explain how force is related to changes in momentum.
4. Explain the law of conservation of momentum and how it relates to Newton's third law.

3.2 Energy and the Conservation of Energy

Energy is one of the fundamental quantities in our universe. Without energy, nothing could ever change. Yet pure energy itself cannot be smelled, tasted, touched, seen, or heard. However, energy does appear in many forms, such as motion and heat. Energy can travel in different ways, such as in light and sound waves and in electricity. The workings of the universe (including all of our technology) can be viewed from the perspective of energy flowing from one place to another and changing back and forth from one form to another.

What is energy?

A definition of energy

Energy is a quantity that measures the ability to cause change. Anything with energy can change itself or cause change in other objects or systems. Energy can cause changes in temperature, speed, position, momentum, pressure, or other physical variables. Energy can also cause change in materials, such as burning wood changing into ashes and smoke.

Energy is a quantity that measures the ability to cause change in a physical system.

Examples

- A gust of wind has energy because it can move objects in its path.
- A piece of wood in a fireplace has energy because it can produce heat and light.
- You have energy because you can change the motion of your own body.
- Batteries have energy because they can be used in a radio to make sound.
- Gasoline has energy because it can be burned in an engine to move a car.
- A ball at the top of a hill has energy because it can roll down the hill and move objects in its path.

Units of energy

The unit of measurement for energy is the **joule (J)**. One joule is the energy needed to push with a force of one newton over a distance of one meter (Figure 3.9). The joule is an abbreviation for one newton multiplied by one meter. If you push on your calculator with a force of one newton while it moves a distance of one meter across a table, one joule of your energy is converted into the energy of the calculator's motion.

Vocabulary

energy, joule, work, potential energy, kinetic energy, law of conservation of energy

Objectives

- ✓ Describe work and energy.
- ✓ Calculate potential energy.
- ✓ Calculate kinetic energy.
- ✓ Apply the law of conservation of energy to explain the motion of an object acted on by gravity.

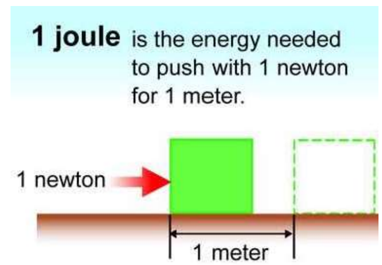


Figure 3.9: *Pushing with a force of one newton over a distance of one meter requires one joule of energy.*

Calories

The *Calorie* is a unit of energy often used for food. One Calorie equals 4,187 joules.

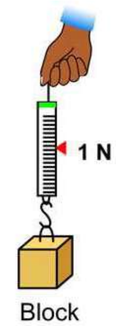
Table of Contents

What is work?

"Work" means different things

The word "*work*" is used in many different ways.

- You should always check over your *work* before handing in a test.
- You go to *work*.
- Your toaster doesn't *work*.
- You *work* with other students on a group project.



What "work" means in physics

In physics, **work** has a very specific meaning. Work is the transfer of energy that results from applying a force over a distance. To calculate work you multiply the force by the distance the object moves in the direction of the force. If you lift a block with a weight of one newton for a distance of one meter, you do one joule of work. One joule of energy is transferred from your body to the block, changing the block's energy. Both work and energy are measured in the same units because work is a form of energy.

Work is done on objects

When thinking about work you should always be clear about which force is doing the work on which object. Work is done *on* objects. If you lift a block one meter with a force of one newton, you have done one joule of work *on the block* (Figure 3.10).

WORK

$$W = Fd$$

Work (joules) = *Force* (newtons) × *Distance* (meters) in the direction of the force

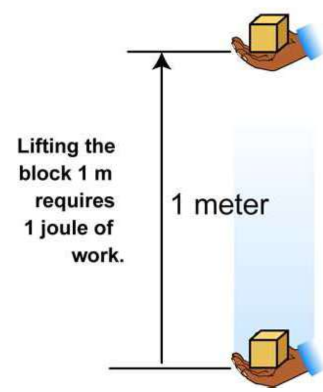


Figure 3.10: *When you lift a 1-newton block a height of 1 meter, you do 1 joule of work on the block.*

Energy is needed to do work

An object that has energy is able to do work; without energy, it is impossible to do work. In fact, one way to think about energy is as *stored work*. A falling block has kinetic energy that can be used to do work. If the block hits a ball, it will do work on the ball and change its motion. Some of the block's energy is transferred to the ball during the collision.

Potential energy

What is potential energy? **Potential energy** is energy due to *position*. The word “potential” means that something is capable of becoming active. Systems or objects with potential energy are able to exert forces (exchange energy) as they change to other arrangements. For example, a stretched spring has potential energy. If released, the spring will use this energy to move itself (and anything attached to it) back to its original length.

Gravitational potential energy A block above a table has potential energy. If released, the force of gravity moves the block down to a position of lower energy. The term *gravitational potential energy* describes the energy of an elevated object. The term is often shortened to just “potential energy” because the most common type of potential energy in physics problems is gravitational. Unless otherwise stated, you can assume “potential energy” means gravitational potential energy.

How to calculate potential energy How much potential energy does a raised block have? The block’s potential energy is exactly the amount of work it can do as it goes down. Work is force multiplied by distance. The force is the weight (*mg*) of the block in newtons. The distance the block can move down is its height (*h*) in meters. Multiplying the weight by the distance gives you the block’s potential energy at any given height (Figure 3.11).

POTENTIAL ENERGY

$$E_p = mgh$$

- E_p: *Potential energy* (joules)
- m: *Mass* (kg)
- g: *Acceleration due to gravity* (9.8 m/sec^2)
- h: *Height* (meters)

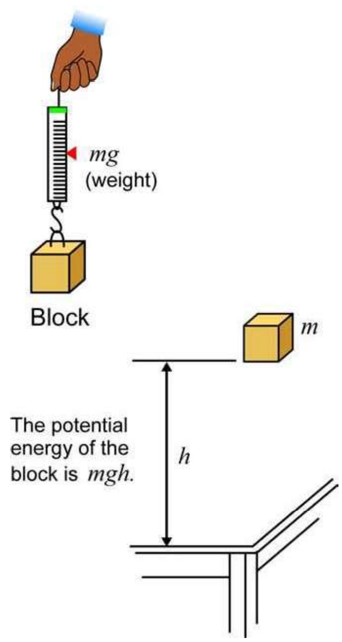


Figure 3.11: *the potential energy of the block is equal to the product of its mass, the strength of gravity, and the height the block can fall from.*

Table of Contents

Kinetic energy

Kinetic energy is energy of motion

Objects that are moving also have the ability to cause change. Energy of *motion* is called **kinetic energy**. A moving billiard ball has kinetic energy because it can hit another object and change its motion. Kinetic energy can easily be converted into potential energy. The kinetic energy of a basketball tossed upward converts into potential energy as the height increases.

Kinetic energy can do work

The amount of kinetic energy an object has equals the amount of work the object can do by exerting force as it stops. Consider a moving skateboard and rider (Figure 3.12). Suppose it takes a force of 500 N applied over a distance of 10 meters to slow the skateboard down to a stop (500 N × 10 m = 5,000 joules). The kinetic energy of the skateboard and rider is 5,000 joules since that is the amount of work it takes to stop the skateboard.

Kinetic energy depends on mass and speed

If you had started with twice the mass — say, two skateboarders — you would have to do twice as much work to stop them both. Kinetic energy increases with mass. If the skateboard board and rider are moving faster, it also takes more work to bring them to a stop. This means kinetic energy also increases with speed. Kinetic energy is related to *both* an object's speed and its mass.

The formula for kinetic energy

The kinetic energy of a moving object is equal to one half its mass multiplied by the square of its speed. This formula comes from a combination of relationships, including Newton's second law, the distance equation for acceleration ($d = {}^1/_2 at^2$), and the calculation of energy as the product of force and distance.

KINETIC ENERGY

$$E_k = \frac{1}{2} m v^2$$

Kinetic energy (joules) → E_k; *Mass* (kg) → m; *Speed* (m/sec) → v

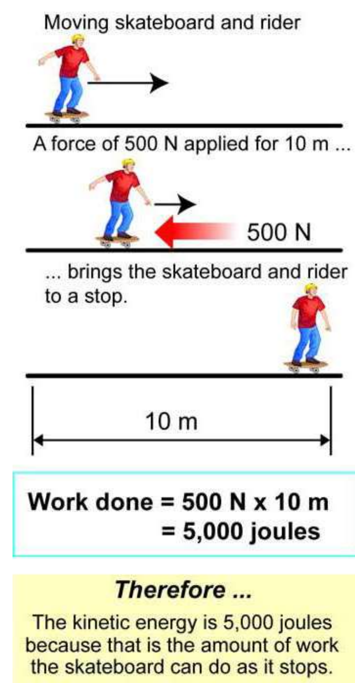


Figure 3.12: *The amount of kinetic energy the skateboard has is equal to the amount of work the moving board and rider can do as they come to a stop.*

Kinetic energy increases as the square of the speed

Kinetic energy increases as the square of the speed. This means that if you go twice as fast, your energy increases by four times ($2^2 = 4$). If your speed is three times as fast, your energy is nine times bigger ($3^2 = 9$). A car moving at a speed of 100 km/h (62 mph) has *four times* the kinetic energy it had when going 50 km/h (31 mph). At a speed of 150 km/h (93 mph), it has *nine times* as much energy as it did at 50 km/h. The stopping distance of a car is proportional to its kinetic energy. A car going twice as fast has four times the kinetic energy and needs four times the stopping distance. This is why driving at high speeds is so dangerous.

Figure 3.13: *Stopping distances.*

Potential and kinetic energy

A 2 kg rock is at the edge of a cliff 20 meters above a lake. It becomes loose and falls toward the water below. Calculate its potential and kinetic energy when it is at the top and when it is halfway down. Its speed is 14 m/sec at the halfway point.

1. Looking for: You are asked for the potential and kinetic energy at two locations.

2. Given: You are given the mass in kilograms, the height at each location in meters, and the speed halfway down in m/sec. You can assume the initial speed is 0 m/sec because the rock starts from rest.

3. Relationships: $E_p = mgh$ and $E_k = \frac{1}{2}mv^2$

4. Solution:

Potential energy at the top: $m = 2$ kg, $g = 9.8$ N/kg, and $h = 20$ m
$E_p = (2 \text{ kg})(9.8 \text{ N/kg})(20 \text{ m}) = 392 \text{ J}$

Potential energy halfway down: $m = 2$ kg, $g = 9.8$ N/kg, and $h = 10$ m
$E_p = (2 \text{ kg})(9.8 \text{ N/kg})(10 \text{ m}) = 196 \text{ J}$

Kinetic energy at the top: $m = 2$ kg and $v = 0$ m/sec
$E_k = (1/2)(2 \text{ kg})(0^2) = 0 \text{ J}$

Kinetic energy halfway down: $m = 2$ kg and $v = 14$ m/sec
$E_k = (1/2)(2 \text{ kg})(14 \text{ m/sec})^2 = 196 \text{ J}$

Your turn...

a. Calculate the potential energy of a 4 kilogram cat crouched 3 meters off the ground. **Answer:** 117.6 J

b. Calculate the kinetic energy of a 4 kilogram cat running at 5 m/sec. **Answer:** 50 J

Table of Contents

Conservation of energy

Energy converts from potential to kinetic

What happens when you throw a ball straight up in the air (Figure 3.14)? The ball leaves your hand with kinetic energy it gained while your hand accelerated it from rest. As the ball goes higher, it gains potential energy. However the ball slows down as it rises so its kinetic energy *decreases*. The increase in potential energy is exactly equal to the decrease in kinetic energy. The kinetic energy converts into potential energy, and the ball's total energy stays the same.

Law of conservation of energy

The idea that energy converts from one form into another without a change in the total amount is called the **law of conservation of energy**. The law states that energy can never be created or destroyed, just converted from one form into another. The law of conservation of energy is one of the most important laws in physics. It applies to not only kinetic and potential energy, but to all forms of energy.

Energy can never be created or destroyed, just converted from one form into another

Using energy conservation

The law of conservation of energy explains how a ball's launch speed affects its motion. As the ball in Figure 3.14 moves upward, it slows down and loses kinetic energy. Eventually it reaches a point where all the kinetic energy has been converted to potential energy. The ball has moved as high as it will go and its upward speed has been reduced to zero. If the ball had been launched with a greater speed, it would have started with more kinetic energy. It would have had to climb higher for all of the kinetic energy to be converted into potential energy. If the exact launch speed is given, the law of conservation of energy can be used to predict the height the ball reaches.

Energy converts from kinetic to potential

The ball's conversion of energy on the way down is opposite what it was on the way up. As the ball falls, its speed increases and its height decreases. The potential energy decreases as it converts into kinetic energy. If gravity is the only force acting on the ball, it returns to your hand with exactly the same speed and kinetic energy it started with — except that now it moves in the opposite direction.

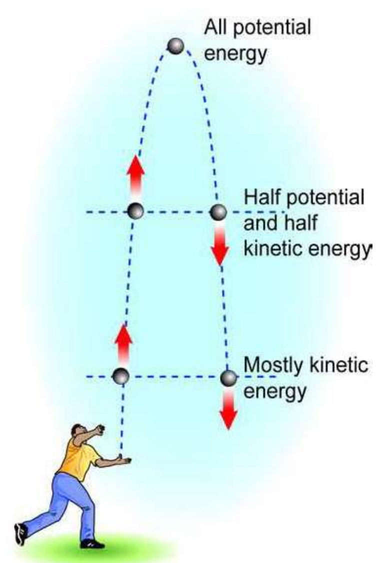


Figure 3.14: *When you throw a ball in the air, the energy transforms from kinetic to potential and then back to kinetic.*

Table of Contents

Using energy conservation to solve problems

How to use energy conservation

Energy conservation is a direct way to find out what happens before and after a change (Figure 3.15) from one form of energy into another. The law of energy conservation says the total energy before the change equals the total energy after it. In many cases (with falling objects, for instance), you need not worry about force or acceleration. Applying energy conservation allows you to find speeds and heights very quickly.

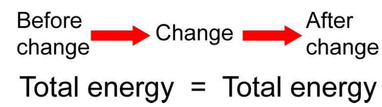
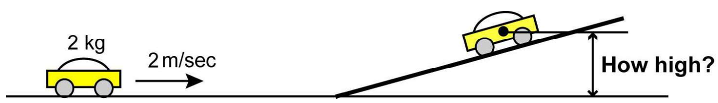


Figure 3.15: *Applying energy conservation.*

Energy conservation

A 2 kg car moving with a speed of 2 m/sec starts up a hill. How high does the car roll before it stops?



1. Looking for: You are asked for the height.

2. Given: You are given the mass in kilograms, and starting speed in m/sec.

3. Relationships: From the law of conservation of energy, the sum of kinetic and potential energy is constant. The ball keeps going uphill until all its kinetic energy has been turned into potential energy.

$$E_K = \frac{1}{2}mv^2 \quad , E_P = mgh$$

4. Solution: Find the kinetic energy at the start:
$E_K = (1/2)(2\text{ kg})(2\text{ m/sec})^2 = 4\text{ J}$
Use the potential energy to find the height
$mgh = 4\text{ J}$ therefore:
$h = (4\text{ J}) \div ((2\text{ kg})(9.8\text{ N/kg}))$
$= 0.2\text{ m}$
The car rolls upward to a height of 0.2 m above where it started

Your turn...

a. A 500 kg roller coaster car starts from rest at the top of a 60-meter hill. Find its potential energy when it is halfway to the bottom. **Answer:** 147,000 J

b. A 1 kg ball is tossed straight up with a kinetic energy of 196 J. How high does it go? **Answer:** 20 m

Table of Contents

“Using” and “conserving” energy in the everyday sense

“Conserving” energy Almost everyone has heard that is good to “conserve energy” and not waste it. This is good advice because energy from gasoline or electricity costs money and uses resources. But what does it mean to “use energy” in the everyday sense? If energy can never be created or destroyed, how can it be “used up”? Why do smart people worry about “running out” of energy?

“Using” energy When you “use” energy by turning on a light, you are really converting energy from one form (electricity) to other forms (light and heat). What gets “used up” is the amount of energy *in the form of electricity.* Electricity is a valuable form of energy because it is easy to move over long distances (through wires). In the “physics” sense, the energy is not “used up” but converted into other forms. The total amount of energy stays constant.

Power plants Electric power plants don’t *make* electrical energy. Energy cannot be created. What power plants do is convert other forms of energy (chemical, solar, nuclear) into electrical energy. When someone advises you to turn out the lights to conserve energy, they are asking you to use less electrical energy. If people used less electrical energy, power plants would burn less oil, gas, or other fuels in “producing” the electrical energy they sell.

“Running out” of energy Many people are concerned about “running out” of energy. What they worry about is running out of certain *forms* of energy that are easy to use, such as oil and gas. When you use gas in a car, the chemical energy in the gasoline mostly becomes heat energy. It is impractical to put the energy back into the form of gasoline, so we say the energy has been “used up” even though the energy itself is still there, only in a different form.

3.2 Section Review

1. What are the units of energy and what do they mean?
2. What is work in physics and what is the relationship between work and energy?
3. How can you increase an object’s potential or kinetic energy?
4. What happens to the kinetic and potential energy of a ball as it falls toward the ground?
5. Explain what it means to say energy is conserved.

Please turn out the lights when you leave!

There are about 285,000,000 people living in the United States. If an average house has four light bulbs per person, it adds up to 1,140,000,000 light bulbs. The average bulb uses 100 joules of electrical energy each second. Multiplying it out gives an estimate of 114,000,000,000 joules every second, just for light bulbs!

A big electric power-plant puts out 2,000,000,000 joules each second. That means 67 big power plants are burning up resources just to run your light bulbs. If everyone were to switch their incandescent bulbs to fluorescent lights we would save 75 percent of this electricity. That means we could save 50 big power plants’ worth of pollution and wasted resources!

3.3 Collisions

A **collision** occurs when two or more objects hit each other. When we hear the word collision, we often picture cars crashing. But a collision also takes place when a tennis ball hits a racket, your foot hits the ground, or your fingers press on a keyboard. During a collision, momentum and energy are transferred from one object to another. Different factors like mass, initial velocity, and the type of collision determine the velocity of objects after they collide. In this section, you will learn about the two types of collisions, elastic and inelastic, and the momentum and energy changes that result.

Vocabulary

collision, elastic collision, inelastic collision

Objectives

- ✓ Distinguish between elastic and inelastic collisions.
- ✓ Use momentum conservation to solve collision problems.
- ✓ Explain how momentum, impulse, force, and time are related.

Elastic and inelastic collisions

Elastic collisions

There are two main types of collisions, elastic and inelastic. When an **elastic collision** occurs, objects bounce off each other with no loss in the total kinetic energy of the system. The total kinetic energy before the collision is the same as the total kinetic energy after the collision. The collision between billiard balls is very close to a perfectly elastic collision (Figure 3.16).

Inelastic collisions

In an **inelastic collision**, objects change shape or stick together, and the total kinetic energy of the system decreases. The energy is not destroyed, but it is transformed into forms other than kinetic energy, such as permanently changing shape. An egg hitting the floor is one example of an inelastic collision; two vehicles colliding is another. In both cases, some of the kinetic energy is used to permanently change an object's shape.

Perfectly elastic collisions

Collisions you see in everyday life are mixed. When two billiard balls collide, it looks like they bounce without a loss of kinetic energy. But the sound of the collision tells you a small amount of kinetic energy is being changed into sound energy. However, we approximate the collision as elastic because it is more like an elastic collision than an inelastic one. The balls bounce and do not change shape. Perfectly elastic collisions *do* occur on a smaller scale. The collision between two individual atoms in the air is an example of a perfectly elastic collision. No kinetic energy is transformed into heat or sound. These collisions are responsible for the air pressure that keeps a balloon inflated.

Figure 3.16: *The collision of two billiard balls is elastic. The collision of an egg with the floor is inelastic.*

Table of Contents

Momentum conservation in collisions

Elastic and inelastic collisions

As long as there are no outside forces (such as friction), momentum is conserved in both elastic and inelastic collisions. This is true even when kinetic energy is not conserved. Conservation of momentum makes it possible to determine the motion of objects before or after colliding.

Problem-solving steps

Using momentum to analyze collisions takes practice. Use the steps below to help you find solutions to problems.

1. Draw a diagram.
2. Decide whether the collision is elastic or inelastic.
3. Assign variables to represent the masses and velocities of the objects before and after the collision.
4. Use momentum conservation to write an equation stating that the total momentum before the collision equals the total after. Then solve it.

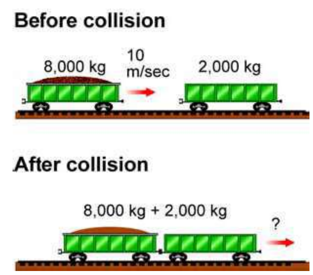


Figure 3.17: *An inelastic collision of two train cars.*

Momentum and collisions

An 8,000-kg train car moves to the right at 10 m/sec. It collides with a 2,000-kg parked train car (Figure 3.17). The cars get stuck together and roll along the track. How fast do they move after the collision?

1. Looking for: You are asked for the velocity of the train cars after the collision.

2. Given: You are given both masses in kilograms and the initial velocity of the moving car in m/sec. You know the collision is inelastic because the cars get stuck together.

3. Relationships: Apply the law of conservation of momentum. Because the two cars get stuck together, consider them to be a single giant train car after the collision. The final mass is the sum of the two individual masses.
initial momentum of car 1 + initial momentum of car 2 = final momentum of combined cars
$m_1v_1 + m_2v_2 = (m_1+m_2)v_3$

4. Solution: $(8{,}000 \text{ kg})(10 \text{ m/sec}) + (2{,}000 \text{ kg})(0 \text{ m/sec}) = (8{,}000 \text{ kg} + 2{,}000 \text{ kg})v_3$
$v_3 = 8$ m/sec. The train cars move to the right together at 8 m/sec.

Your turn...

a. Repeat the above problem but with each car having a mass of 2000 kg. **Answer:** 5 m/sec

b. A 5-kg bowling ball with a velocity of +10 m/sec hits a stationary 2-kg bowling pin. If the ball's final velocity is +8 m/sec, what is the pin's final velocity? **Answer:** +5 m/sec

Forces in collisions

Collisions involve forces Collisions create forces because the colliding objects change their motion. Since collisions take place quickly, the forces change rapidly and are hard to measure directly. However, momentum conservation can be used to estimate the forces in a collision. Engineers need to know the forces so they can design things not to break when they are dropped.

Force and collisions A rubber ball and a clay ball are dropped on a gymnasium floor (Figure 3.18). The rubber ball has an elastic collision and bounces back up with the same speed it had when it hit the floor. The clay ball has an inelastic collision, hitting the floor with a thud and staying there. Both balls have the same mass and are dropped from the same height. They have the same speed as they hit the floor. Which ball exerts a greater force on the floor?

Force changes momentum The total change in momentum is equal to the force multiplied by the time during which the force acts. Because force and time appear as a pair, we define the impulse to be the product of force and time.

Bounces have greater momentum change Suppose each ball shown in Figure 3.18 has a mass of 1 kilogram and hits the floor at a velocity of -5 m/sec (negative is downward). The momentum of the clay ball changes from -5 kg·m/sec to zero. This is a change of 5 kg·m/sec. The rubber ball also starts with a momentum of -5 kg·m/sec. If the collision is perfectly elastic, it bounces up with the same momentum but in the opposite direction. Its momentum then goes from -5 kg·m/sec to +5 kg·m/sec, a change of +10 kg·m/sec. The rubber ball (elastic collision) has twice the change in momentum (Figure 3.19). The momentum change is always greater when objects bounce compared with when they do not bounce.

Bouncing vs. stopping Because we don't know the collision times, it is impossible to calculate the forces exactly. We can only say for certain that the impulse (force × time) is 10 N·sec for the rubber ball. This could be a force of 10 N for 1 second, or 100 N for 0.1 seconds, or any combination that results in 10 N·sec. However, we can be pretty sure the force from the rubber ball is greater because the momentum of the rubber ball changed twice as much as the momentum of the clay ball. Bouncing nearly always results in a greater force than just stopping because bouncing creates a larger change in momentum.

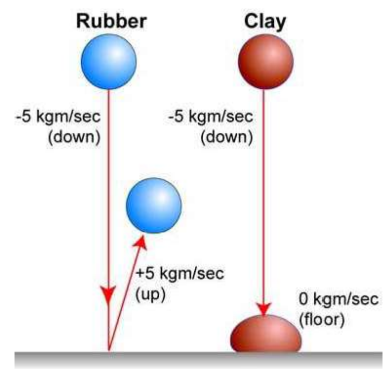


Figure 3.18: *Bouncing results in a greater change in momentum and therefore almost always creates a greater force.*

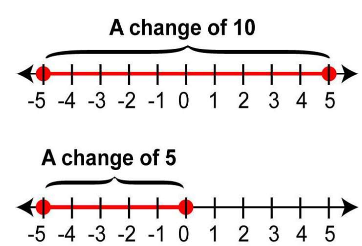


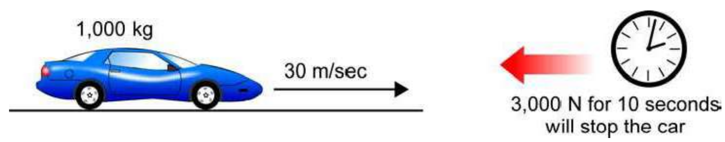
Figure 3.19: *A number line can help you see clearly that a change from -5 to +5 is twice as great as a change from -5 to 0.*

Table of Contents

Solving impulse problems

Motion problems

Impulse can be used to solve many practical problems. For example, how much force does it take to stop a 1,000-kilogram car in 10 seconds if the car is moving at 30 m/sec (67 mph)? To solve this kind of problem, calculate the change in momentum, then use the impulse to calculate the force. For the car, the change in momentum is 30,000 kg·m/sec (1,000 kg × 30 m/sec). That means the impulse must be 30,000 N·sec. Since you know the time is 10 seconds, the force is 3,000 N because 3,000 N × 10 sec = 30,000 N·sec.



Collision force problems

If you know the time during which the colliding objects touch each other you can calculate the average force of the collision. The maximum force is larger than the average because forces in collisions tend to rise as the colliding objects come together, reach a maximum, and then drop off as the objects move apart. However, knowing the average force is useful.

Why does impulse equal the force multiplied by the time?

To find the relationship between momentum, force, and time, start with Newton's second law:

$$F = ma$$

Substituting for acceleration:

$$F = m\frac{(v_2 - v_1)}{t}$$

Rearranging:

$$Ft = m(v_2 - v_1)$$
$$Ft = mv_2 - mv_1$$

Therefore the change in momentum (impulse) equals the product of the force and time.

Impulse

A 1 kg clay ball hits the floor with a velocity of -5 m/sec and comes to a stop in 0.1 second. What force did the floor exert on it?

2. Given: You are given the ball's mass, initial speed, final speed, and stopping time.

3. Relationships: $Ft = mv_2 - mv_1$

4. Solution:

$$F(0.1\text{ sec}) = (1\text{ kg})(0\text{ m/sec}) - (1\text{ kg})(-5\text{ m/sec})$$
$$F(0.1\text{ sec}) = 5\text{ kg}\cdot\text{m/sec}$$
$$F = 50\text{ N}$$

Your turn...

a. What braking force is needed to stop a 1000 kg car moving at 30 m/sec in a time of 2 seconds? **Answer:** 15,000 N

b. You pedal your bicycle with a force of 40 N. If you start from rest and have a mass of 50 kg, what is your final speed after 10 seconds? **Answer:** 8 m/sec

Car crash safety

Stopping in an accident The relationship between impulse, force, and time has been used by auto manufacturers to make vehicles safer in accidents. When a car crashes to a stop, its momentum drops to zero. The shorter the amount of stopping time, the greater the force on the car. Car bodies are designed to crumple in an accident to extend the stopping time. The ideal car crumples enough to stop gradually, but not so much that the passenger compartment is affected.

Seat belts The stopping time of a car in a collision is very short even when crumpling occurs. A passenger without a seat belt will have a momentum that drops from a large value to zero when hitting the windshield, steering wheel, or dashboard. Seat belts are made of a very strong fabric that stretches slightly when a force is applied. Stretching extends the time over which the passenger comes to a stop and results in less force being exerted on the person's body.

Air bags Air bags work together with seat belts to make cars safer (Figure 3.20). An air bag inflates when the force applied to the front of a car reaches a dangerous level. The air bag deflates slowly as the person's body applies a force to the bag upon impact. The force of impact pushes the air out of small holes in the air bag, bringing the person to a gradual stop. Many cars now contain both front and side air bags.

Crash test dummies Automakers use crash test dummies to study the effects of collisions on passengers (Figure 3.21). Crash test dummies contain electronic sensors to measure the forces felt in various places on the body. Results of these tests have been used to make changes in automobile design, resulting in cars that are much safer than they were in the past.

Figure 3.20: *Seat belts and air bags work together to safely stop passengers in automobile collisions.*

Figure 3.21: *Crash test dummies are used in car safety tests.*

3.3 Section Review

1. List three examples of elastic collisions and three examples of inelastic collisions not mentioned in this chapter.
2. Are momentum and kinetic energy conserved in all collisions?
3. What is the definition of impulse?
4. Why will an egg break if it is dropped on the ground but not if it is dropped on a pillow?

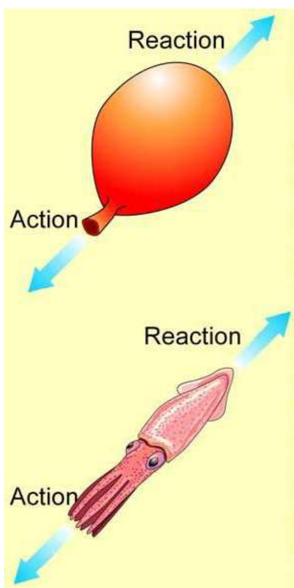
Rockets: Out of This World Travel

What if you wanted to travel to space? What type of vehicle would get you there? Your vehicle would need to reach incredible speeds to travel huge distances. Speed is also important in overcoming the gravitational pull of planets, moons, and the sun. Your vehicle would need to be able to travel in a *vacuum* because space has no air. It would also need a very powerful engine to get into space.

So what would be your vehicle of choice? A rocket, of course!

Rockets and Newton's third law

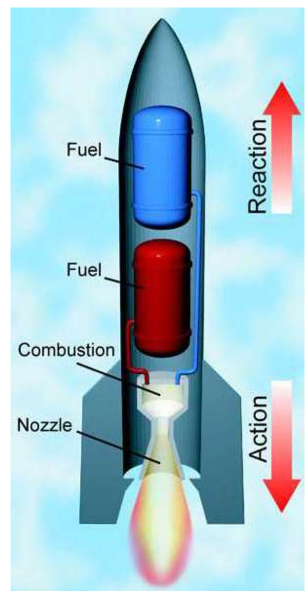
A rocket is a vehicle with a special type of engine. The basic principle behind how a rocket works is Newton's third law, *for every action, there is an equal and opposite reaction.*



What happens when you blow up party balloon, then let it go, allowing the air to blow out the open end? The balloon darts around the room, travelling through the air. With the balloon, the *action* is the air being expelled. The *reaction* is the movement of the balloon in the opposite direction. Another example is the movement of squid. A squid takes water into its body chamber and rapidly expels it out of backward-directed tube. What are the action and reaction forces in this example?

Rocket science

The action/reaction forces demonstrated by the balloon and squid, are the main idea behind how a rocket engine works. A rocket engine forces material out the nozzle in one direction causing the rocket to move in the opposite direction.



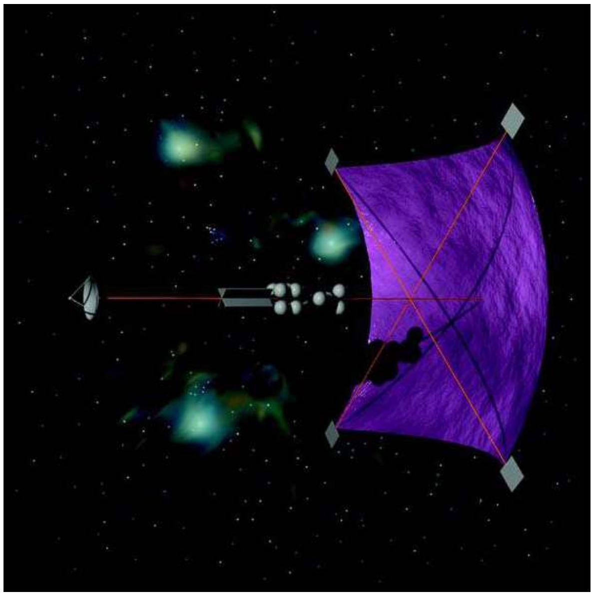
The mass that is ejected in a rocket's exhaust is the same as the mass of fuel that is burned. The speed of the fuel is very high, often more than 1,000 meters per second. Since the backward-moving fuel carries negative momentum, the rocket must increase its positive momentum to keep the total momentum constant.

To break free from Earth's gravity and get into space, a rocket must reach a speed of over 40,250 kilometers per hour (called *escape velocity*). Attaining this speed requires a rocket engine to achieve the greatest possible action force, or *thrust*, in the shortest time. To do this, the engine must burn a large mass of fuel and push the gas out as fast as possible. The fuel required to achieve this thrust weighs over 30 times more than the rocket and its payload (what it carries). Rockets that travel into space are so huge because you need to carry lots of fuel!

Table of Contents

Rocket scientists

Robert Goddard (1882 to 1945), an American scientist, concluded that it was possible to travel to space by applying the kind of thrust demonstrated by the balloon example. Goddard was able to take his ideas beyond theory and actually designed and built rockets. In fact he launched the first liquid-fueled rocket in 1926. Perhaps more importantly, Goddard proved rockets can propel objects in a vacuum. This touched off a revolution in thinking about space travel that continues to this day. His patents and technology innovations would solve the large problems of rockets in space. There are over 200 patents from Goddard's work.



A little help from gravity

In August 2004, NASA launched MESSENGER, a spacecraft headed for the planet Mercury. The entire trip will cover almost 7.9 billion kilometers (5.9 billion miles) rounding the sun 15 times. At 1,100 kilograms, MESSENGER is considered lightweight for a rocket. While more than half of the weight is fuel, it would not be enough to cover this great distance without some external help. Thankfully, not all of the trip is to be powered by the energy of the rocket. MESSENGER will get a slight boost from the sun and different planets it passes.

While rocket technology will continue to power the space exploration industry for years to come, we need to develop newer energy sources or whole new technologies to take us deeper into space. Scientists estimate that if we were to travel to distant regions of our own solar system using today's fuel technologies, 99% of the spacecraft launch weight would have to be fuel and only 1% would be payload. Can you think of ways to do this without having to carry so much fuel on board?

The future of rockets

Some new technologies being developed and tested for deep space travel minimize the fuel storage burden, by having their energy sources located behind them. One of these technologies uses the particles from the sun as a "wind" to accelerate the spacecraft like a sail boat. Another idea uses extremely light gases for fuels to reduce the mass required and increase the distances that can be covered. Still another idea is to find ways to accelerate atomic particles to extremely high speeds, creating thrust more efficiently. Even with these advanced technologies, all rockets rely on the ideas in Newton’s laws.

Questions:

1. Is a rocket’s thrust the action or reaction force?
2. Why are rockets for deep space travel so huge?
3. How is a rocket engine different than an automobile engine?
4. What are the major obstacles to bringing humans deeper into space?

Chapter 3 Review

Table of Contents

Understanding Vocabulary

Select the correct term to complete the sentences.

energy	momentum	elastic collision
work	inelastic collision	kinetic energy
Newton's third law	joule	potential energy
law of conservation of energy	collision	impulse
law of conservation of momentum		

Section 3.1

1. The ____ states that the total amount of momentum in a closed system cannot change.
2. ____ is calculated by multiplying a force and the time needed for the force to act.
3. According to ____, for every action force, there is a reaction force equal in strength and opposite in direction.
4. The mass of an object multiplied by its velocity equals its ____.

Section 3.2

5. The ____ states that energy can never be created or destroyed, just changed from one form to another.
6. The unit of energy needed to push with a force of one newton over a distance of one meter is one ____.
7. Energy due to position is known as ____.
8. Energy of motion is called ____.
9. ____ is needed to cause change to an object, such as changing its speed or height.
10. ____ is force times distance moved in the direction of the force.

Section 3.3

11. When two or more objects hit each other, a ____ occurs.
12. When two objects collide and stick together or change shape, it is called a(n) ____.
13. Two billiard balls bouncing off each other is an example of a(n) ____.

Reviewing Concepts

Section 3.1

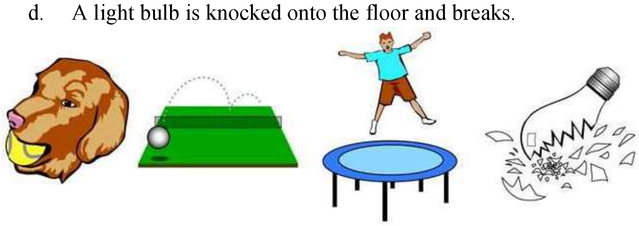
1. State Newton's third law in your own words.
2. Action and reaction forces always have the _____ strength and act in _____ directions.
3. You and a friend are sitting across from each other on chairs with wheels. You push off each other and move in opposite directions. Explain the following:
   a. How does the force you feel compare to the force your friend feels?
   b. If your mass is greater than your friend's mass, how do your accelerations compare?
4. A book rests on a table. The force of gravity pulls down on the book. What prevents the book from accelerating downward?
5. Give three examples of Newton's third law in everyday life. List the action and reaction forces in each example.
6. What two things does an object require to have momentum?
7. Consider an airplane at rest and a person walking through the airport.
   a. Which has greater mass?
   b. Which has greater velocity?
   c. Which has greater momentum? Explain.
8. Explain the two different ways to calculate impulse.
9. Is the unit used represent impulse the same as the unit for momentum? Explain.
10. State the law of conservation of momentum in your own words.
11. You and your little cousin are standing on inline skates. You push off of each other and both move backwards.
    a. Which of you moves back at a greater speed? Use the law of conservation of momentum to explain your answer.
    b. How does your impulse compare to your cousin's impulse?
12. When you jump, you move upward with a certain amount of momentum. Earth moves downward with an equal amount of momentum. Why doesn't anyone notice the Earth's motion?

Section 3.2

13. What is anything with energy able to do?
14. The joule is an abbreviation for what combination of units?
15. When work is done, _____ is transferred.
16. How can you increase the gravitational potential energy of an object?
17. Explain why a bicycle at rest at the top of a hill has energy.
18. Which two quantities are needed to determine an object's kinetic energy?
19. What happens to a car's kinetic energy if its speed doubles? What if its speed triples?
20. A ball is thrown up into the air. Explain what happens to its potential and kinetic energies as it moves up and then back down.
21. Explain what it means to say energy is conserved as a ball falls toward the ground.
22. Will we ever run out of energy on Earth? Might we run out of certain forms of energy? Explain.

Section 3.3

23. Distinguish between elastic and inelastic collisions.
24. Classify each collision as elastic or inelastic.
    a. A dog catches a tennis ball in his mouth.
    b. A ping-pong ball bounces off a table.
    c. You jump on a trampoline.
    d. A light bulb is knocked onto the floor and breaks.

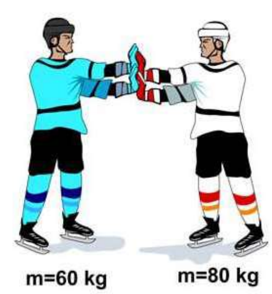


25. Is momentum conserved during elastic collisions? Is it conserved during inelastic collisions?
26. Why does bouncing nearly always cause a greater force than simply stopping during a collision?
27. Cars that crumple in a collision are safer than cars that bounce when they collide. Explain why this is so.
28. What is the secret to catching a water balloon without breaking it? Explain using physics.

Solving Problems

Section 3.1

1. You throw a basketball by exerting a force of 20 newtons. According to Newton's third law, there is another 20-newton force created in the opposite direction. If there are two equal forces in opposite directions, how does the ball accelerate?
2. What is the momentum of a 2-kg ball traveling at 4 m/sec?
3. How fast does a 1000 kg car have to move to have a momentum of 50,000 kg-m/sec?
4. Idil's momentum is 110 kg-m/sec when she walks at 2 m/sec. What's her mass?
5. Which has more momentum: a 5000-kg truck moving at 10 m/sec or a sports car with a mass of 1200 kg moving at 50 m/sec?
6. Two hockey players on ice skates push off of each other. One has a mass of 60 kilograms. The other has a mass of 80 kilograms.
    a. If the 80-kilogram player moves back with a velocity of 3 m/sec, what is his momentum?
    b. What is the 60-kilogram player's momentum?
    c. What is the 60-kilogram player's velocity?



7. A 75 kg astronaut floating in space throws a 5 kg rock at 5 m/sec. How fast does the astronaut move backwards?

Table of Contents

8. A 2-kilogram ball is accelerated from rest to a speed of 8 m/sec.
   a. What is the ball's change in momentum?
   b. What is the impulse?
   c. A constant force of 32 newtons is used to change the momentum. For how much time does the force act?

9. A 1000-kg car uses a braking force of 10,000 N to stop in 2 seconds.
   a. What impulse acts on the car?
   b. What is the change in momentum of the car?
   c. What was the initial speed of the car?

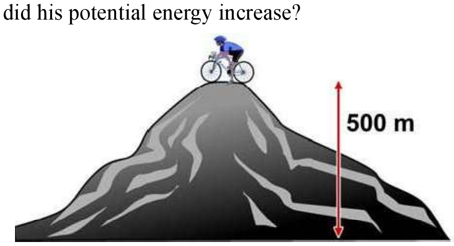
Section 3.2

10. A 5-kg can of paint is sitting on top of a 2-meter high step ladder. How much work did you do to move the can of paint to the top of the ladder? What is the potential energy of the can of paint?

11. How much work is done to move a 10,000-N car 20 meters?

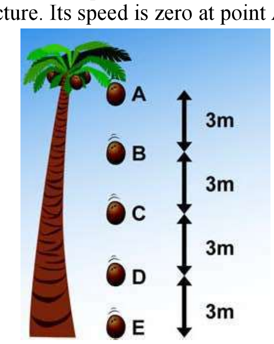
12. Which has more potential energy, a 5 kg rock lifted 2 meters off the ground on Earth, or the same rock lifted 2 meters on the moon? Why?

13. At the end of a bike ride up a mountain, Chris was at an elevation of 500 meters above where he started. If Chris's mass is 60 kg, by how much did his potential energy increase?



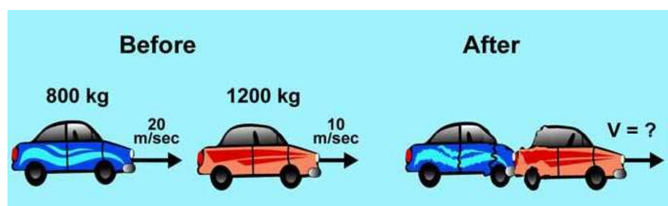
14. Alexis is riding her skateboard. If Alexis has a mass of 50 kg:
   a. What is her kinetic energy if she travels at 5 m/sec?
   b. What is her kinetic energy if she travels at 10 m/sec?
   c. Alexis's 50 kg dog Bruno gets on the skateboard with her. What is their total kinetic energy if they move at 5 m/sec?
   d. Based on your calculations, does doubling the mass or doubling the speed have more of an effect on kinetic energy?

15. A 1-kilogram coconut falls out of a tree from a height of 12 meters. Determine the coconut's potential and kinetic energy at each point shown in the picture. Its speed is zero at point A.



Section 3.3

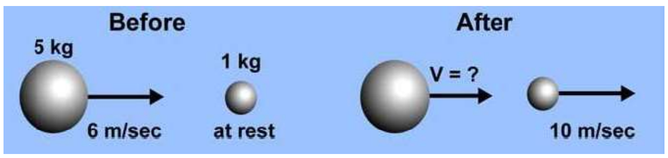
16. A demolition derby is a car-crashing contest. Suppose an 800-kg car moving at 20 m/sec crashes into the back of and sticks to a 1200-kg car moving at 10 m/sec in the same direction.



   a. Is this collision elastic or inelastic? Why?
   b. Calculate the momentum of each car before the collision.
   c. What is the total momentum of the stuck together cars after the collision? Why?
   d. What is the speed of the stuck together cars after the collision?

Table of Contents

17. A 5-kg ball moving at 6 m/sec collides with a 1-kg ball at rest. The balls bounce off each other and the second ball moves in the same direction as the first ball at 10 m/sec. What is the velocity of the first ball after the collision?



18. Yanick and Nancy drive two identical 1500-kilogram cars at 20 m/sec. Yanick slams on the brakes and his car comes to a stop in 1 second. Nancy lightly applies the brakes and stops her car in 5 seconds.
    a. How does the momentum change of Yanick's car compare to the momentum change of Nancy's car?
    b. How does the impulse on Yanick's car compare to the impulse on Nancy's car?
    c. How does the force of Yanick's brakes compare to the force of Nancy's brakes?
    d. Calculate the stopping force for each car.
19. Your neighbor's car breaks down. You and a friend agree to push it two blocks to a repair shop while your neighbor steers. The two of you apply a net force of 800 newtons to the 1000-kilogram car for 10 seconds.
    a. What impulse is applied to the car?
    b. At what speed is the car moving after 10 seconds? The car starts from rest.

Applying Your Knowledge

Section 3.1

1. Think up some strange scenarios that might happen if the universe changed so that Newton's third law were no longer true.
2. Identify at least *three* action-reaction force pairs in the picture of the firefighter below.

3. The greatest speed with which an athlete can jump vertically is around 5 m/sec. Determine the speed at which Earth would move down if you jumped up at 5 m/sec.

Section 3.2

4. A car going twice as fast requires four times as much stopping distance. What is it about the kinetic energy formula that accounts for this fact?
5. The energy is food is measured in Calories rather than joules. One Calorie is equal to 4187 joules. Look on the nutrition labels of three of your favorite foods. Determine the amount of energy in joules in one serving of each type of food.

Section 3.3

6. Major League Baseball requires players to use wooden bats, and does not allow the use of aluminum bats. Research to find out why this is. Relate what you find to what you learned in this chapter.
7. Use the internet to learn more about how cars are designed to be safer in collisions and how they are tested. Make a poster that summarizes what you learn.