3 Using Newton's Laws

TEKS 4(A), 4(C), 4(D), 4(E)

What You'll Learn

- how Newton's first law explains what happens in a car crash
- how Newton's second law explains the effects of air resistance
- when momentum is conserved

Before You Read

Imagine riding on a sled, or in a wagon, or perhaps a school bus that stops quickly or suddenly. What happens to your body if you are not expecting the sudden stop? Describe the motion and feeling on the lines below.

Focus →
Make a List of 10 things that help you use Newton's laws.

Read to Learn

What happens in a crash?

The law of inertia can explain what happens in a car crash. Imagine that a car traveling at 50 km/h (approximately 30 mph) crashes head-on into a stationary object. It crumples and comes to a stop within 0.1 s. Passengers who are not wearing safety belts continue to move forward at the same speed the car was traveling. Within about 0.02 s after the car stops, the unbelted passengers slam into the dashboard, steering wheel, windshield, or the backs of the front seats. They are still moving at the original speed of 50 km/h. This is about the same speed they would reach falling from a three-story building.

How do safety belts help?

A person who is wearing a safety belt will be attached to the car. The person will slow down as the car slows down. Safety belts also prevent people from being thrown out of cars. About half of the people who die in car crashes would have survived if they had been wearing safety belts. Thousands of others would suffer fewer serious injuries.

What about air bags?

Since the late1990s all new cars have air bags. Designed to protect the front seat occupants from injury during collisions, air bags inflate and then deflate again in one twenty-fifth of a second. Some newer cars even have air bags for side collisions. Like seat belts, air bags save lives by preventing people from being thrown out of cars. They reduce the acceleration of the passengers.

Newton's Second Law and Gravitational Acceleration

If you dropped a marble and a bowling ball at the same time, which one would hit the ground first? Suppose the effects of air resistance were small enough to be ignored. When all forces except gravity can be ignored, a falling object is said to be in free fall. If there were no air resistance, all objects near Earth's surface would fall with the same acceleration. The marble and the bowling ball would hit the ground at the same time.

The acceleration of an object in free fall is about 9.8 m/s^2. This acceleration is sometimes called the acceleration of gravity. It is given the symbol *g*. The force of Earth's gravity on a falling object is the object's mass times the acceleration of gravity. This can be expressed by the following equation.

force of gravity (N) = **mass** (kg) × **acceleration of gravity** (m/s^2)

$$F = mg$$

You can use this equation to find the gravitational force on a sky diver with a mass of 60 kg.

$$F = mg = (60\ \text{kg})(9.8\ \text{m/s}^2) = 588\ \text{N}$$

The gravitational force on the sky diver is 588 N.

What is air resistance?

Objects falling toward Earth are being pulled downward by the force of gravity. **Air resistance** is a force that opposes the movement of objects through the air. Air resistance is similar to friction. You can feel air resistance on your face when you ride your bike very fast.

Like friction, air resistance acts in the direction opposite to the object's motion. In the case of a falling object, air resistance pushes up as gravity pulls down. If there were no air resistance, only gravity would affect falling objects. All objects would fall at the same rate.

Air resistance causes different objects to fall with different accelerations and different speeds. The amount of air resistance depends on an object's size and shape. Imagine dropping two identical plastic bags. One is crumpled into a ball and the other is spread out, resembling a parachute. When the bags are dropped, the crumpled bag falls faster than the spread-out bag. The downward force of gravity on both bags is the same. But, the upward force of air resistance on the crumpled bag is less. So, the net downward force on the crumpled bag is greater.

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Apply Math

1. **Calculate** Find the weight of a 50-kg person on Earth. Remember, $g = 9.8 m/s^2$. Show your work.

GET IT?

2. **Explain** why some objects fall faster than others.

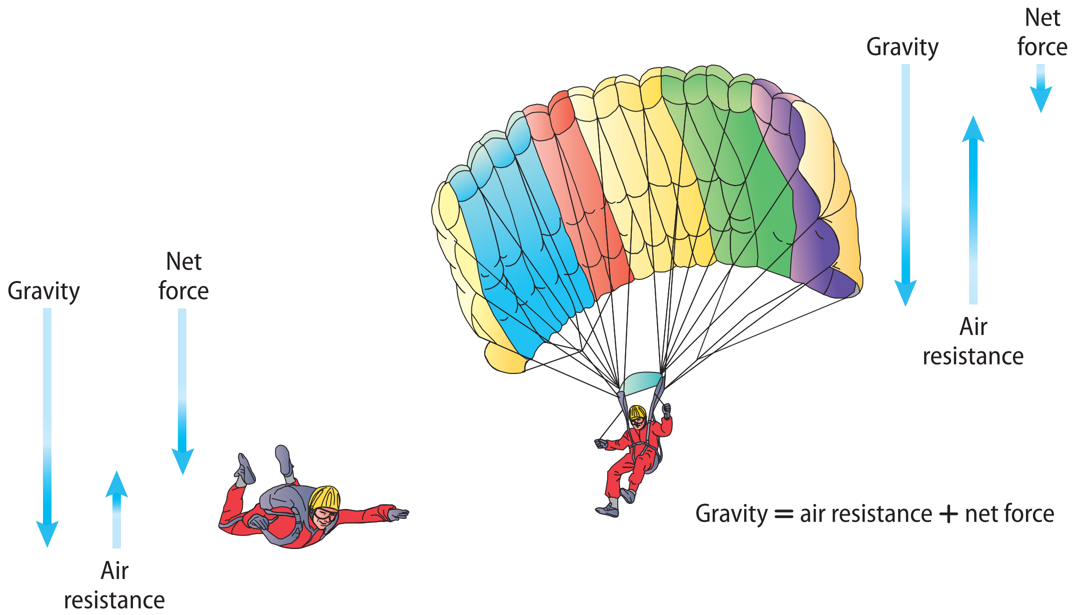
What is terminal velocity?

Imagine an object falling toward Earth. As the object falls, gravity causes it to accelerate. This causes the upward force of air resistance to increase. At some point, the upward force of air resistance becomes equal to the downward force of gravity. This means that the net force is zero. So, from this point on, the object will fall at a constant speed. This constant speed is called terminal velocity. **Terminal velocity** is the highest speed a falling object can reach. The terminal velocity of an object depends on its size, shape, and mass.

Look at the figure below. The air resistance force on an open parachute is much greater than the air resistance on the sky diver with a closed parachute. With the parachute open, air resistance increases. This makes the terminal velocity of the sky diver become small enough that the sky diver can land safely.

Take a Look

3. Compare Measure the length of each arrow beside the sky diver. Compare the length of the gravity arrow to the lengths of the air resistance and net force arrows.



Weightlessness and Free Fall

Suppose you are standing on a scale in an elevator that is not moving. The scale would record your normal weight. But, what would happen if you were standing on the scale and the elevator were falling rapidly? If gravity was the only force acting on you and the scale, you would be in **free fall**. The dial would say you have zero weight, even though your weight has not changed. You might say you are weightless.

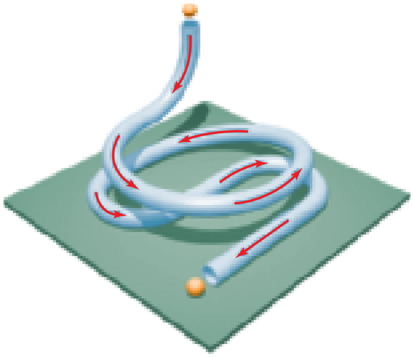
You may have seen pictures of astronauts floating inside a space shuttle. They are experiencing weightlessness. The astronauts are not really weightless. In orbit of Earth, the astronauts are in a constant state of free fall.

Think it Over

4. Explain Why do astronauts in the space shuttle weigh less?

Centripetal Forces

Look at the path of the ball as it travels through the curved tube in the figure below. When the ball enters a curve, even if its speed does not change, it is accelerating. This is because its direction is changing. When the ball goes through a curve, the change in its direction is toward the center of the curve. Acceleration toward the center of a curved path is called **centripetal acceleration**.



The ball has centripetal acceleration. So, according to the second law of motion, the direction of the net force on the ball must be toward the center of the curved path. The net force exerted toward the center of a curved path is called a **centripetal force**. An object that moves in a circle is doing so because a centripetal force is acting on it in a direction toward the center. The centripetal force is the force exerted by the walls of the tube on the ball.

Take a Look

5. Trace the path of the ball at right with a pen. Try to move the pen at a constant speed.

How does centripetal force depend on traction?

When a car rounds a curve, a centripetal force must be acting on the car to keep it moving in a curved path. If it does not, the car will slide off the road. This centripetal force is the frictional force, or traction, between the tires and the road. The road may be slippery because of rain or ice. As tires get older, they get smoother and their traction decreases. If either or both of these situations occur, the car may slide in a straight line and not follow the curve. This is because the centripetal force, traction, is not strong enough to keep the car moving around the curve.

Think it Over

6. Describe a real-world situation that involves centripetal force.

Can gravity be a centripetal force?

Imagine swinging a yo-yo on a string above your head. The string places centripetal force on the yo-yo. The string keeps the yo-yo moving in a circle. In the same way, Earth's gravitational pull places centripetal force on the Moon and keeps it moving in a nearly circular orbit.

Force and Momentum

A moving object has a property called momentum. Momentum is related to how much force is needed to change an object's motion. The **momentum** of an object is the product of its mass and its velocity.

What is the law of conservation of momentum?

Momentum can be passed from one object to another. When a cue ball hits a group of balls that are motionless, the cue ball slows down and the other balls move. The momentum that the group of balls gained equals the momentum that the cue ball lost. But the total momentum of all the balls before and after the collision is the same. Total momentum has not been lost, nor has new momentum been created. This is an example of the **law of conservation of momentum**. If a group of objects applies forces on each other, their total momentum does not change.

Think it Over

7. Recognize Cause and Effect In a game of pool, why will the balls eventually stop after a collision?

What happens when objects collide?

In a game of pool, suppose one ball is moving in one direction, and another ball moving the same direction strikes it from behind. The ball that is struck will continue to move in the same direction, but more quickly. The striking ball has given it more momentum in the same direction.

What if two balls of equal mass are moving toward each other with the same speed? They would have the same momentum, but in opposite directions. If the balls collided, each would reverse direction, and move with the same speed as before the collision.

What is rocket propulsion?

Suppose you are standing on skates holding a softball. You exert a force on the softball when you throw it. Newton's third law says the softball exerts a reaction force on you. This force pushes you in the direction opposite the softball's motion.

Rockets use this same principle to move. In a rocket engine, burning fuel produces hot gases. The rocket engine applies a force on the gases and causes them to escape out of the back of the rocket. By Newton's third law, the gases apply a reaction force on the rocket and push it in the opposite direction.

After You Read

Mini Glossary

air resistance: a friction-like force opposing objects moving in air

centripetal force: a force exerted toward the center of a curved path

free fall: when gravity is the only force acting on an object

law of conservation of momentum: if a group of objects exerts forces only on each other, their total momentum does not change

terminal velocity: the maximum velocity an object will reach while falling through air

Review

1. Study the terms and their definitions in the Mini Glossary. Describe a real-world example of the law of conservation of momentum.

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2. Match the terms with the correct statements. Put the letter of the statement in Column 2 on the line in front of the term it matches in Column 1.

Column 1

_____ **1.** rocket propulsion

_____ **2.** momentum

_____ **3.** conservation of momentum

_____ **4.** Newton's third law of motion

Column 2

a. To every action force there is an equal and opposite reaction.

b. Momentum cannot be created or destroyed.

c. the product of a moving object's mass and velocity

d. An engine applies a force on hot gases and the gases apply a force in the opposite direction.

3. You created a list of things that help you use Newton's laws. How do these examples teach you Newton's laws?

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