Ode to the Olympics:
Winter Edition

5th Grade

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Ode to the Olympics: Winter Edition

** Has an Answer Sheet*

Winter Olympics
VOCABULARY

Acceleration - the rate at which velocity changes over time

Aerodynamic - having a shape or design that reduces **drag** from air

Angular Momentum (Angular Velocity) - the velocity of a mass in rotation

Axis - the line about which something rotates

Center of Gravity (Center of Mass) - the point at which the weight of an object seems to be concentrated

Conservation of Angular Momentum - angular momentum stays constant (if there is no **torque**)

Centripetal Force - a force that makes a body follow a curved path instead of a straight one

Centrifugal Force - a sensation that comes from an object's **inertia** resisting rotation

Kinetic Energy - the energy an object has when it's in motion

Lever Arm (Moment Arm) - perpendicular distance from an axis to the line of direction in which the force is acting

Mass - a measurement of how much matter is in an object; mass can be determined by how much an object weighs—the more mass an object has, the more **inertia** it has

Moment of Inertia - a body's tendency to resist angular **acceleration**

Momentum - the product of the mass and velocity of an object

Newton - a unit for measuring force. One newton exerted for one second will accelerate 1 kilogram of mass by one meter per second

Deformation - the change in size or shape of an object due to a force

Drag (Air Resistance) - a force acted on a solid object in the direction of the flow of a fluid

Force - any influence that causes an object to change in some way

Friction - a force caused when two things slide against each other

Gravitational Acceleration - acceleration caused by gravity

Gravity - a force which tries to pull two objects toward each other

Inertia - the tendency of an object to resist changes in its motion, including direction; the more **mass** an object has, the more inertia it has

Newton's First Law - an object at rest stays at rest and an object in motion stays in motion with the same speed and in the same direction unless acted on by an unbalanced force

Newton's Third Law - for every action, there is an equal and opposite reaction

Angular Momentum (Angular Velocity) - the velocity of a mass in rotation

Linear Momentum (Linear Velocity) - the velocity, direction, and mass of an object

Potential Energy - the stored energy of an object

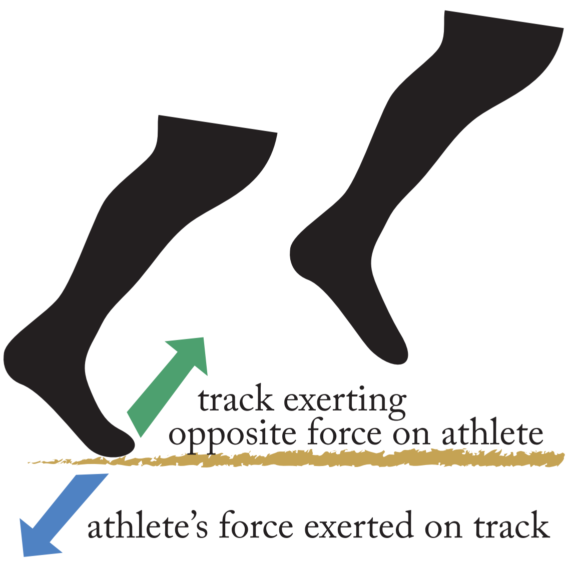
Torque - a force that causes an object to rotate

Velocity - equal to an object's speed and direction of motion

Winter Olympics
Bobsled

What makes Olympic bobsledding different than just sledding down a hill on a snow day? You might be surprised by all the things bobsledders have to consider to speed past the finish line in the shortest time.

At the beginning of the race is the "pushoff." During the pushoff, bobsledders run as fast as they can while holding onto the sled for 50 meters before jumping inside. As the athletes are running, their feet are applying **force** to the track. This is an example of **Newton's Third Law:** when the athlete exerts a force on the track, the track exerts an equal force on the athlete in the opposite direction. The athletes train and build muscle so that they can create as much force as possible to push the sled forward during that 50 meters and achieve a high **velocity** throughout the race.



After the initial dash, the sledders get into the bobsled one-by-one, keeping it straight and steady so that they don't lose speed. At the 2010 Winter Olympics, the winning time for the four-man bobsled was 3 minutes, 24 seconds, and 46 hundredths of a second. Can you guess the times that earned silver and bronze medals? 3 minutes, 24 seconds, and 84 hundredths of a second, and 3 minutes, 24 seconds, and 85 hundredths of a second!

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03:24:84	
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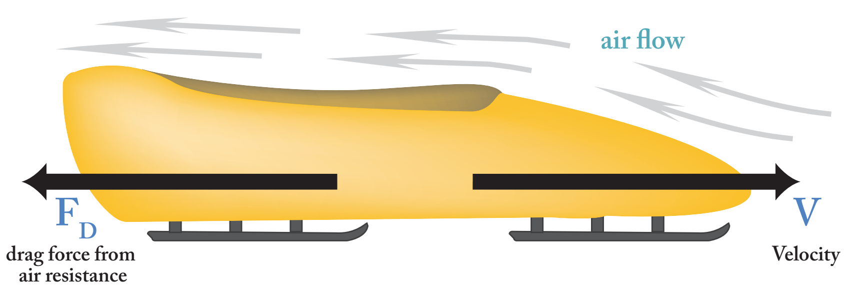
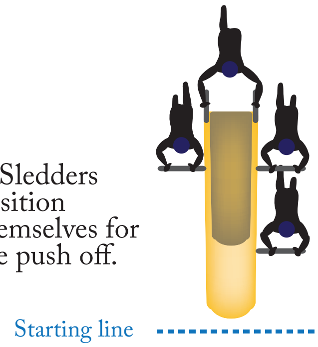
Cool Fact: During a race, bobsledders are going so fast that they experience a force that's five times the force of gravity.

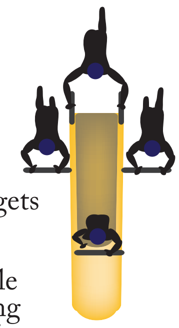
Winter Olympics
Bobsled

For the rest of the race, the team works together to minimize drag due to air resistance, which will reduce their speed. They do this by keeping themselves tucked in as tightly as possible. The body of bobsled is aerodynamic, which means that it's designed so that air flows over it smoothly. You can experience the force of air resistance by (safely!) sticking your hand out the window of a moving car. Even bobsledders' skin-tight suits are aerodynamic to help the team shave off those hundredths of a second to win the race.

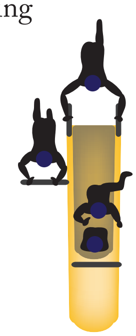




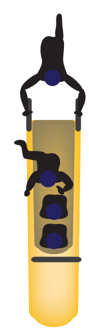
1. Sledders position themselves for the push off.

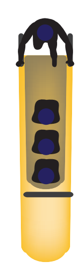


2. The driver gets in first and retracts his pushing handle while preparing to begin steering the sled.

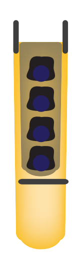


3. Then the pushers, who together apply the most force during the push-off, get in one at a time, also pulling in their handles.





4. The brakeman is the last to get in. He and the pushers tuck their heads in as low as possible to reduce drag on the sled.



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Winter Olympics
Bobsled

Try This!

Experiment with aerodynamics using a paper airplane made out of a sheet of 8.5 by 11 inch printer paper.

Think of the time when you're holding the airplane and winding up to send it sailing through the air as the push-off—for the plane to fly, the plane has to accelerate from rest just like the athletes must get the bobsled moving from rest at the starting line. Like the bobsledders during the push-off, you need to keep the motion of the plane straight and steady, or it'll crash right when you release it.

1. If the paper airplane is travelling fast and smoothly when you're holding it, it will continue to travel in the same way when you let it go. Practice throwing your airplane until you can get it to fly straight and steady several times in a row. Right now, your airplane is very aerodynamic.

2. Cut one-inch slits on each wing along the middle fold. Fold the two flaps upward so that they are at a 90 degree angle from the wing. Throw your modified plane several times.

How does the plane fly after you add the flaps? Does it fly as fast and far as before? Why?

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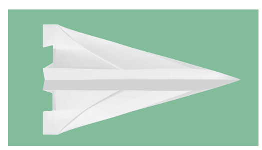

3. If an object has more **mass**, it also has more **inertia**. So when a massive body is in motion, forces of friction have less of an effect on its velocity. For this reason, bobsled teams want to maximize the amount of weight in the bobsled. The weight limit in the four-man bobsled is 630 kg (including athletes and sled). If the team doesn't reach that weight, they are allowed to add metal weights to the sled.

Add a paperclip to the nose of your airplane along the base fold. How does it fly? Why?

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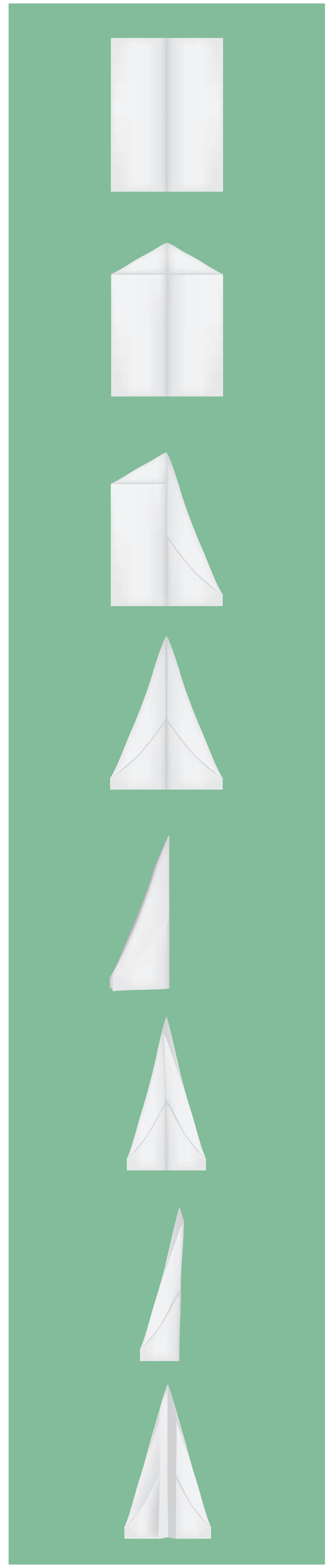
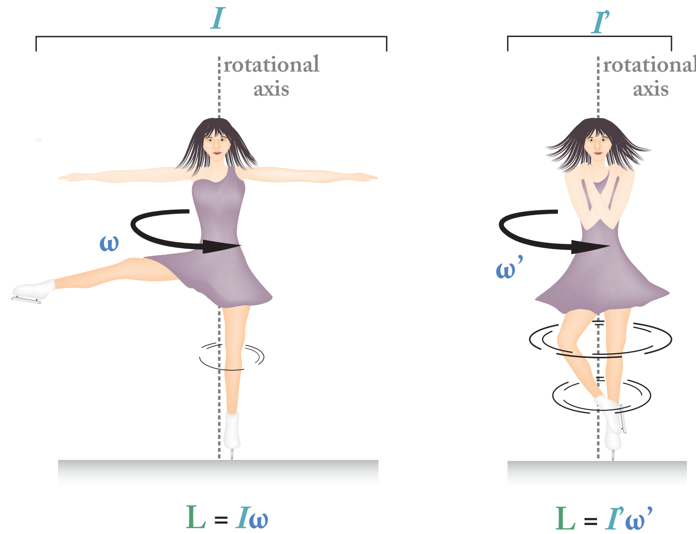


Winter Olympics
Figure Skating

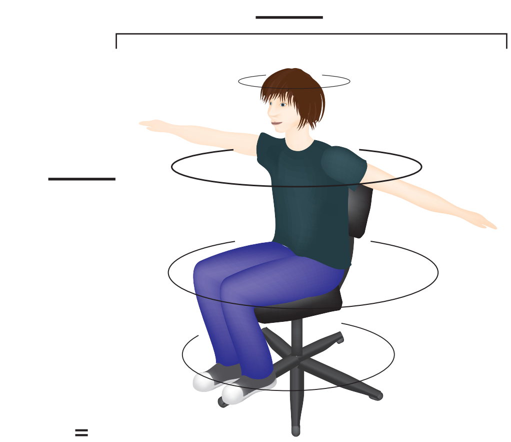
One of the figure skating moves that makes us "ooh" and "aah" is the spin, where the skater rotates in one spot at a dizzying speed. The skater starts the spin with her arms out, and when she tucks them into her body, she goes even faster.

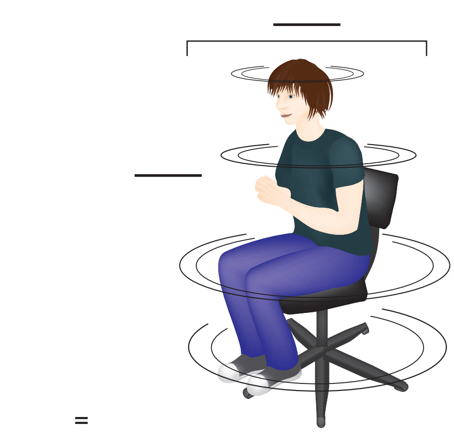
This is due to the law of **conservation of angular momentum**. It's harder to make a mass rotate around an **axis** that's far away than it is to make a mass rotate around an axis that's close. When a skater tucks her arms in, their mass is closer to the axis, so it's easier to rotate—this is called decreasing the **moment of inertia**. Because angular momentum is conserved, her rotation speed must then increase.



L : angular momentum
I : moment of inertia
ω : angular velocity

Label the diagram for the variables:
L : angular momentum
I : moment of inertia
ω : angular velocity





Try This!

1. Set a swiveling chair in an open room, making sure that while sitting in the chair with your arms and legs extended, you won't hit anything.

2. Sit in the chair and begin spinning by pushing off the floor with your foot. Fully extend your arms outward. Keep kicking until you get a good spinning velocity going.

3. Pull in your arms, holding them tightly to your chest. What happens? Why?

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4. Extend your arms outward again. What happens now? Why?

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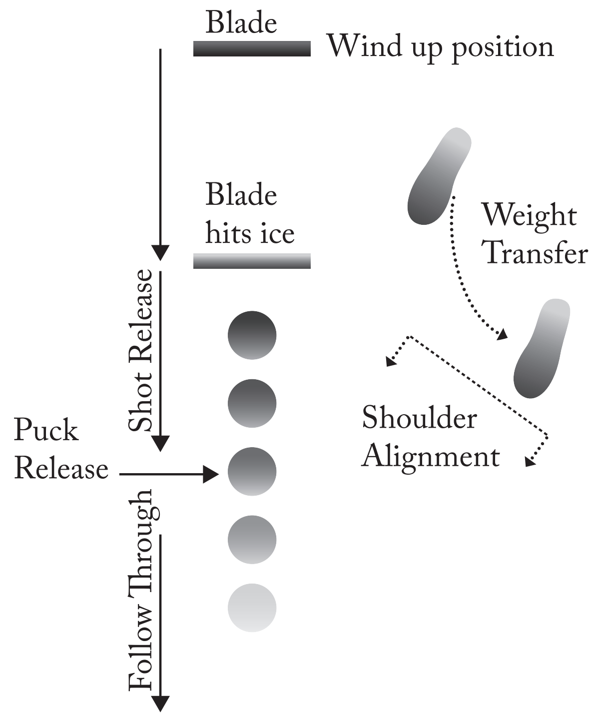
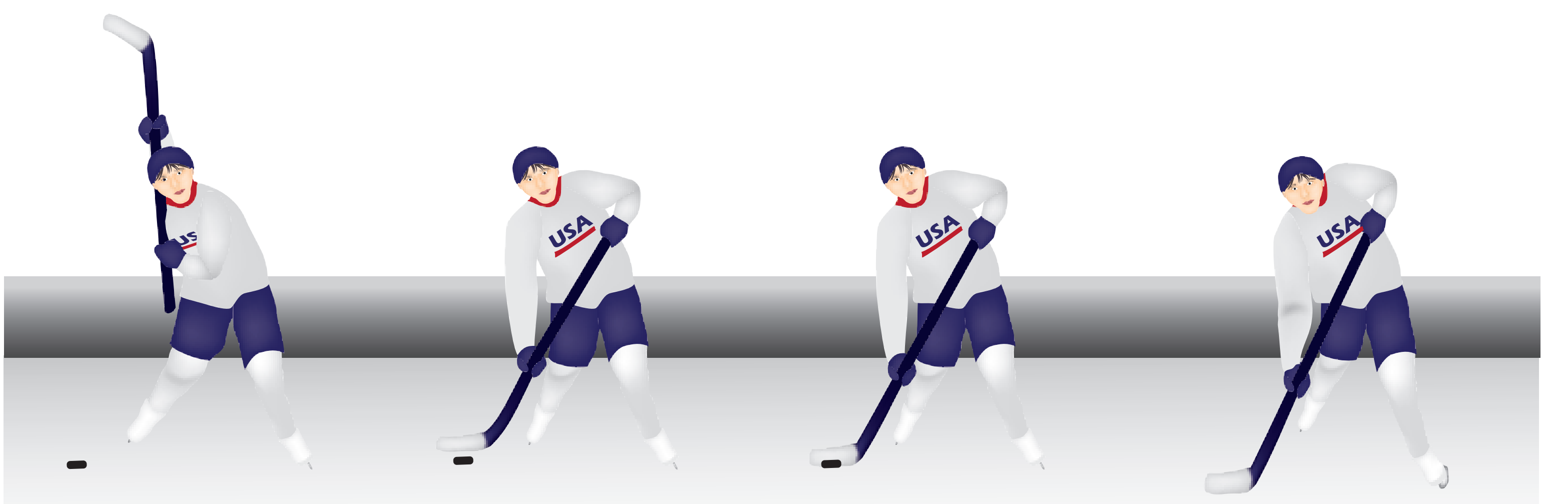
→ You can repeat the experiment with light weights in your hands, like dumbbells or books, to see an even greater effect!

Winter Olympics
Ice Hockey

In ice hockey, the slapshot is the fastest shot players can make, causing the puck to travel around 100 miles per hour! Let's take a look at the physics behind an effective slapshot.



Cool Fact: Most hockey sticks used professionally today are made out of aluminum, carbon graphite, and other materials that are stronger, more flexible, and lighter than wood.



1. Player winds up the hockey stick.

2. Player "slaps" the ice behind the puck, flexing the stick.

3. As the hockey stick blade hits the puck, the player shifts her weight to her forward foot and rolls her wrists to transfer energy to the puck.

4. Puck leaves the blade, and the player follows through

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Winter Olympics
Ice Hockey

Bending the stick against the ice is like compressing a spring. It packs the stick full of **potential energy.** Hockey sticks, like springs and rubber bands, are elastic objects, which means that they're flexible. When the hockey stick is in its usual position, which is straight, there's no stored energy. The hockey stick can be bent some without breaking (this is called **deformation**), but when it's bent, it will try to go back to its normal position. When the stick strikes the puck, that potential energy turns into **kinetic energy**, sending the puck speeding away.

Try This!

1. Get a plastic spoon that can bend about an inch backwards without breaking (biodegradable spoons tend to be more flexible than other plastic spoons).

2. Make a tight wad of paper about half an inch in diameter.

3. Hold the spoon from just the handle and load the wad onto the dip in spoon. Fling the spoon forward and observe how the wad travels through the air.

4. Now, do the same thing, only this time, pull back on the top of the spoon so that the handle bends. Release the spoon and observe how the wad travels through the air. How does this launch compare to the first? How can you explain this?

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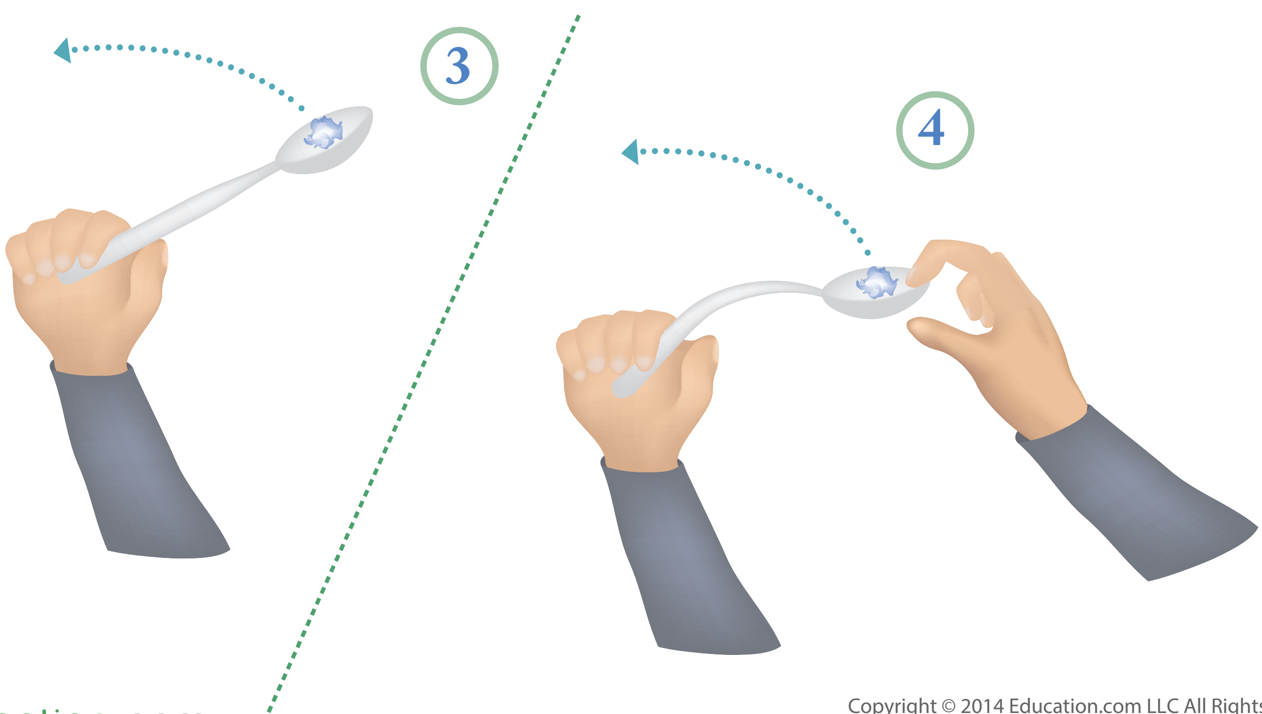
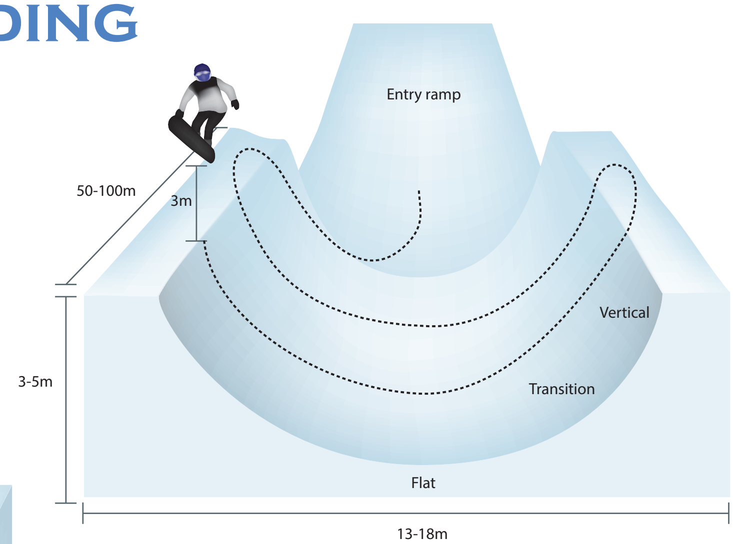
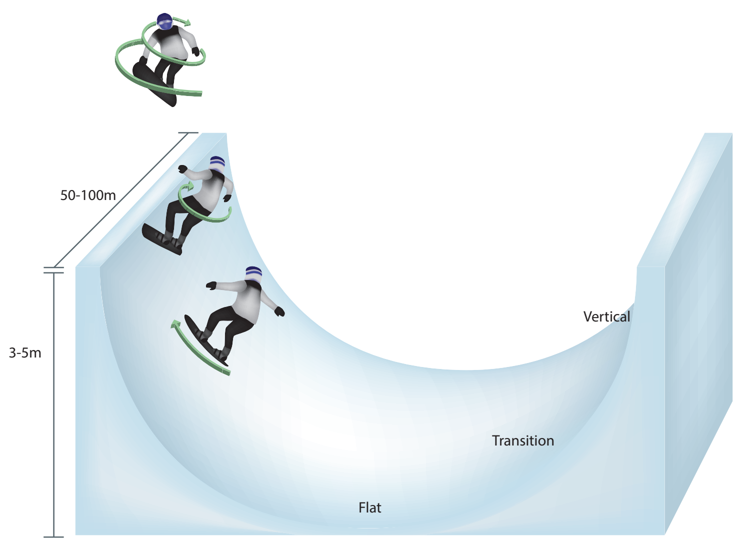


Winter Olympics
Snowboarding

In the snowboard half-pipe event, snowboarders use velocity and torque to perform tricks in the air.





A snowboarder creates torque by twisting his torso at the "vertical" of the half-pipe. This turns linear momentum into angular momentum as he rotates around his own vertical axis.

Try This!

1. Stand up in a clear area. Make sure that you have enough space to reach out both your arms and not touch anything.

2. With your feet about shoulder-width apart, jump straight up. Do this a few times. What kind of momentum is your body experiencing? In what direction?

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3. You're going to jump again, only this time, twist by rotating your chest and shoulders left as you jump. What happened?

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4. Explain how this happened using the terms **linear momentum, angular momentum, torque,** and **axis.**

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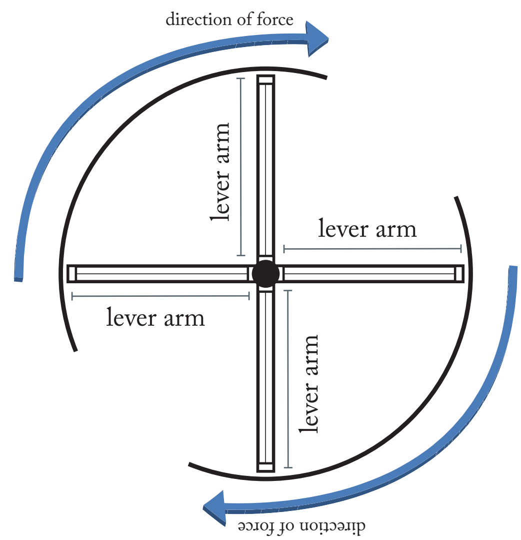
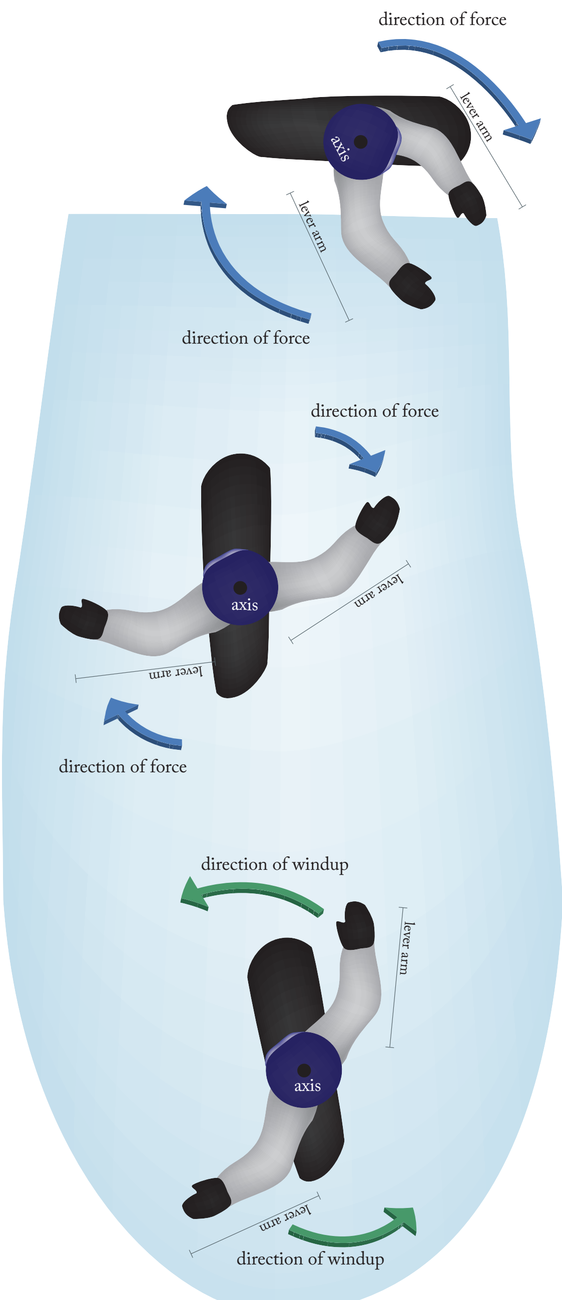
Winter Olympics
Snowboarding

Before a snowboarder does a spin, he extends and "winds up" his arms. By doing this, he's increasing the length of his lever arm, making it easier for his body to rotate. Think about opening a revolving door—is it easier to open by pushing on the edge farthest from the hinge or closer to the hinge? When a snowboarder swings his arms, it increases torque, making it easier for the rest of his body to spin.





Stand in your original position. Without moving your feet, extend your arms away from your body. Point your right arm in front of you and your left arm behind. Your chest and shoulders should be rotated left. Now, as you jump, swing your arms clockwise. How did winding up your arms affect your spin?

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Cool Fact:
If snowboarders maximize their torque on the half-pipe, they can spin up to 600° per second—that's nearly two full spins!

Winter Olympics
Slalom Skiing

Newton's first law says that any moving object wants to continue moving in a straight line at a constant **velocity** (speed). The same is true of athletes on skis. But what happens during events like slalom skiing? Athletes have to complete many quick turns while remaining fast and stable. To do this, alpine skiers use their legs to push on the snow against the force of their own **momentum**—and the more momentum an athlete has, the harder she'll have to push. It isn't unusual for a skier to have to exert hundreds of pounds of force on the snow for several seconds in order to change direction.

So what is momentum, anyway? It's the product of **mass** (weight) and **velocity** (speed), and is represented by the following equation:

$p = mv$

Where:

- **p** = momentum
- **m** = mass
- **v** = velocity

If you're kind of stumped as to how this is all related, here's one way you can think about it. What's an easier thing to stop: a train moving at 30 miles per hour or a marble moving at 30 miles per hour? If you're a good catch, it's pretty easy to snatch the marble out of the air. But if you tried to grab a moving train, the train would just yank you right along with it! Why? The train has a lot more **mass**, meaning it has more **momentum** than the marble—even if their **velocities** are the same.

So what does this mean for skiers? A heavier skier may be able to accelerate faster, because his momentum helps him overcome forces like friction from the snow. Here's the problem, though—in order to turn or come to a full stop, he has to push a whole lot harder on the snow in order to fight against his own momentum!

Try This!

Have a look at the following pairs of moving objects. Which object has the greater momentum? To find out, multiply each object's mass and velocity and pick the larger number.

1. A 7 kg bowling ball traveling at 8 m/s or 0.15 kg baseball travel-ling at 46 m/s

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2. A 92 kg sprinter running at 9 m/s or a 63 kg cyclist on an 11 kg road bike traveling at 12 m/s

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3. A 72 kg alpine snowboarder traveling at 21 m/s or a 61 kg skier traveling at 24 m/s

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Winter Olympics
Slalom Skiing

Check out the illustration above showing a slalom skier during various points of a turn. The red line represents the path that the skier travels in. But remember what Newton's second law says—objects don't naturally travel along curved paths! To complete a turn, a skier has to work hard to change the direction of his **momentum** (represented by the straight blue lines) by using his legs to exert a **force** against the snow with the edge of his skis. The force of the snow pushing back on the skis is represented by the green arrow. (This force has a special name. We'll talk about it more when we explore the physics behind speed skating!)

What else do you notice about the diagram above? Do you notice anything the athlete changes about his body positioning throughout the turn? Take note of his hands, torso, and knees. Why do you think he does this?

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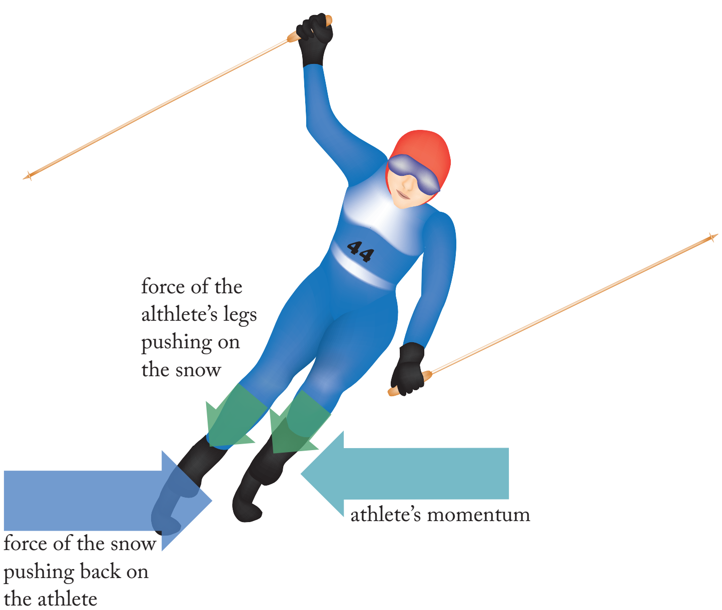
Winter Olympics
Downhill Skiing

Downhill Skiing is less technical than slalom skiing. It involves fewer turns, but athletes ski at much higher speeds. Most courses exceed speeds of 81 mph, and the French athlete Johan Clarey broke the 100 mph barrier on a particularly fast course in 2013.

Check out the diagram illustrating the various **forces** acting on the downhill skier below. She has just triumphantly crossed the finish line, but she's still moving pretty fast! She now has to **decelerate** (slow down) until her **momentum** returns to zero. See how she's turned her skis perpendicular to the direction of her momentum? She does this so that she can exert **force** on the snow with her legs. The snow pushes back with an equal and opposite force, which slows her down. But to come to a complete stop, how much force would she have to exert on the snow, and for how long? Let's find out.



We'll pretend this particular athlete has a **mass** of 62 kilograms, and she crosses the finish line at a **velocity** of 28 meters per second. First, multiply mass and velocity together to get her **momentum**:

62 Kilograms x 28 m/s = ___________________ newton-seconds

The unit we use to measure momentum is **newton-seconds**. Newton-seconds tell us that the athlete's momentum really just comes from **force** measured in **newtons** (in this case, gravity) acting on her over a certain amount of **time**, measured in **seconds**. Gravity has given this athlete a momentum of **1736 newton-seconds**, so we know that she'll need to exert the same amount of force back on the snow in order to stop: **1736 newtons** (which is the same as **390 pounds**) if she wanted to come to a complete stop in one second. Crazy, right? Fortunately, skiers usually have more time to stop than that!

Try This!

How much force is in a newton? Think of it this way: weight is just a measure of how much force gravity exerts on something. There are just over four newtons to a pound. To lift a 5 pound dumbbell, you need to exert just over 22 newtons on it. Practice converting newtons to pounds using the following equation:

1 pound = 4.45 newtons

If a bowling ball weighs 2.2 pounds, it also weighs

______________ newtons.

If your bike weighs 30 pounds, it also weighs

_______________ newtons.

If your textbook weighs 3 pounds, it also

weighs_______________ newtons.

If you weigh ______________ pounds, you also weigh

_______________ newtons.

Winter Olympics
Downhill Skiing

Try This!

Let's try to find out how much force each athlete would have to exert on the snow to come to a complete stop after crossing the finishing line.


Soo-ho, an athlete from the Republic of Korea, skis over the finish line at a speed of 32 meters per second. She weighs 62 kilograms. How much momentum does she have?

62 kilograms x 32 meters per second =

________________ newton-seconds

To find out the average force Soo-ho would have to exert on the snow to stop in three seconds, divide the above result by three:

Soo-ho would have to exert an average force

of_______________ newtons on the snow to come to a complete stop in 3 seconds.


Katja, an athlete from Germany, skis over the finish line at a speed of 35 meters per second. She weighs 64 kilograms. How much momentum does he have?

64kg x 35m/s = _________________________ newton-seconds.

To find out the average force Katja would have to exert on the snow to stop in three seconds, divide the above result by three:

Katja would have to exert an average force

of_______________ newtons on the snow to come to a complete stop in 3 seconds.


Sigmund, an athlete from Norway, skis over the finish line at a speed of 40 meters per second. He weighs 81 kilograms. How much momentum does he have?

81kg x 40m/s = ____________ newton-seconds

To find out the average force Sigmund would have to exert on the snow to stop in three seconds, divide the above result by three:

Sigmund would have to exert an average force

of_______________ newtons on the snow to come to a complete stop in 3 seconds.

Challenge: Divide each result by 4.45 to find out the average force in pounds each athlete would need to exert on the snow to come to a complete stop in 3 seconds. Skiers need strong legs with lots of endurance, and it isn't unusual for some of the top skiers to be able to leg press 800 lbs!

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Winter Olympics
Short Track Speed Skating

In short track speed skating, competitors race each other around an oval track at speeds of up to 40 miles per hour. How do speed skaters lean so sharply during turns without falling over? The athlete pictured below isn't supporting any of his weight on his left hand at all! Remember when we looked at how skiers push on the snow to turn? The force that pushes back is called **centripetal force** because it causes an object to move along a curved path instead of a straight one. Speed skaters turn using this same force, exerted by pushing against the ice with their skates.

Centripetal force leads to an equal and opposite **centrifugal force**. Centrifugal force comes from **inertia**—the tendency of an already-moving object to want to continue moving in a straight line. As the skater turns, he has to work hard to fight against this tendency. Check out the diagram below:

Need an example of how inertia works? Think about braking really hard in a moving car. Your torso gets "thrown" forward into the seat belt, but this feeling just comes from the fact that your torso wants to keep moving, even though the car is stopping!

Here, we can think of gravity and centrifugal force adding up to one big diagonal force (the dashed green arrow) that pulls on the athlete's **center of gravity** (g). As long as the athlete uses his skates to push back up through the ice with an equal and opposite force (the blue arrow), he'll remain perfectly balanced during the turn.

Imagine you're riding as a passenger in a car. When the car makes a really sharp turn, why do you feel like you get yanked in the opposite direction? Use the explanation of centrifugal force provided to help you come up with your answer.

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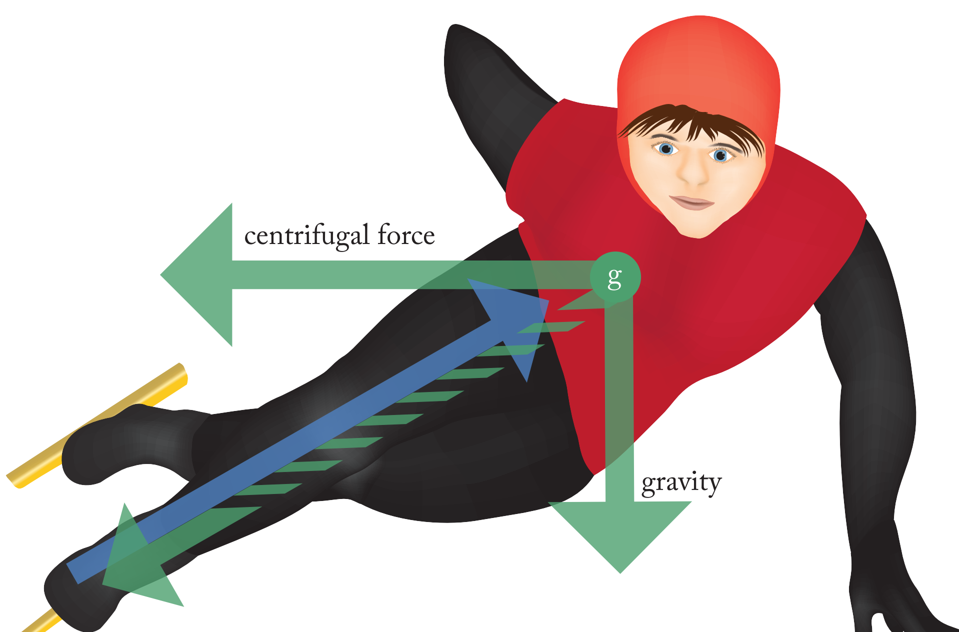


Winter Olympics
Short Track Speed Skating

Try This!

Get a feel for how centripetal and centrifugal forces work! Remember: centripetal force is a push or pull that causes an object to move in a curved path, but because objects have inertia, they resist this pull (remember--moving objects prefer to move in straight lines). We call this resistance centrifugal force.

Procedure

1. Use your permanent marker to mark three evenly spaced points along the edge of your frisbee.

2. Using the hot glue gun, attach one end of each length of fishing line or string to each marked point on the frisbee.

3. Place the plastic cup on the center of the frisbee. Don't glue it down.

4. Tie the loose ends of each string together in a knot.

5. Add about 2 inches of water to the cup. You can add a drop of food coloring if you want—this will make it easier to observe the level of the water as you conduct your experiment.

6. Hold the knot you made in step 4 between your thumb and forefinger.

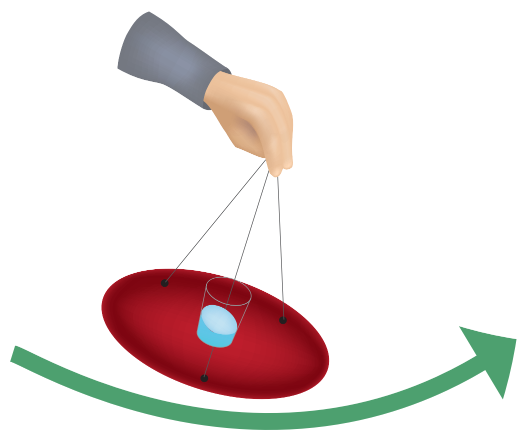
7. Swing the apparatus back and forth, slowly increasing the velocity after each swing. Have a friend observe the level of the water. What happens?

8. Try swinging the apparatus so that the string is parallel to the ground. Why doesn't the water spill out? What's responsible for holding the water in the bottom of the cup?

9. If you're feeling particularly confident, try swinging the apparatus around in a complete circle. If you do it right, the water shouldn't spill out! How come?

Materials

- Three 16" lengths of string or fishing line
- Frisbee
- Hot glue gun
- Plastic cup
- Water
- Food Coloring (optional)
- Permanent marker



Record your observations below, and try to explain the behavior you saw. How can you compare what you observed to how a speed skater keeps his balance during a turn?

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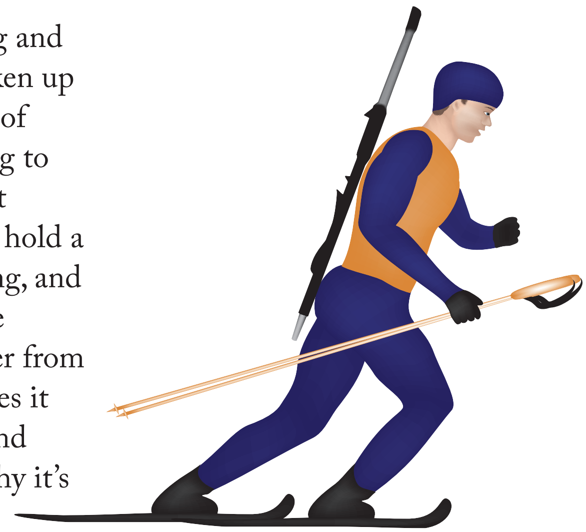
Winter Olympics
Biathlon

Winter biathlon is a sport that combines cross-country skiing and rifle shooting. Biathletes ski around a cross-country trail broken up by two or four rounds of target shooting. During each round of target shooting, athletes face an additional challenge of having to slow their breathing and heart rate because they will have just completed a grueling segment of the race on skis. It's hard to hold a rifle steady when your heart is racing, your muscles are shaking, and you're gasping for breath! To make matters worse, athletes are required to hit circular targets that are only 45mm in diameter from a distance of 50 meters away, sometimes in weather that makes it difficult to see. The unique combination of skill, endurance, and mental focus required in the sport of biathlon help explain why it's the #1 televised winter sport in Europe.

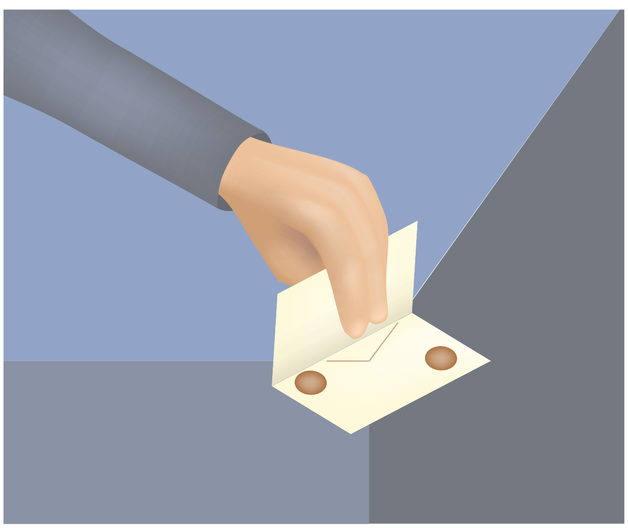


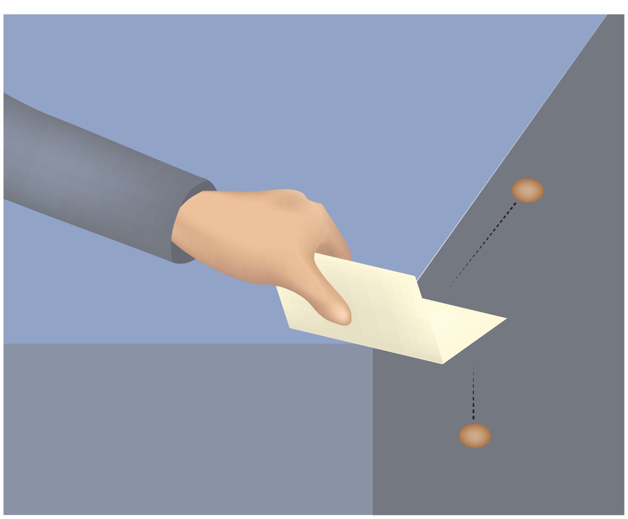
Try This!

Materials

- Table
- 2 coins
- Manila folder

Procedure





1. Cut the folder into a square of about 4 inches a side.

2. Fold the square to make a 2-inch wide flap. Position the flap so that it sticks straight up and down.

3. Place the square on the corner of the table with coins in the positions illustrated below. Grip the square firmly with whichever hand you'd prefer.

4. Now, give the manila folder square a sharp twist to launch one coin sideways while allowing the other to drop straight to the ground.

5. Listen for the sounds of the coins hitting the floor. What do you notice? Record your observations below:

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Winter Olympics
BIATHLON

Try This!

How accurate does a biathlete have to be in order to hit a 45mm target from 50m away?

Materials

- Plastic protractor with a swinging arm
- Laser pointer
- Pencil
- Paper
- Scissors
- Tape

Procedure

1. Cut out the targets below with a pair of scissors and set one up for target practice.

2. Fold along the dotted line to create a stand for your target. Stand your target upright on a flat surface outdoors.

3. Lie in the prone position like a biathlete would about 50 meters away from your target.

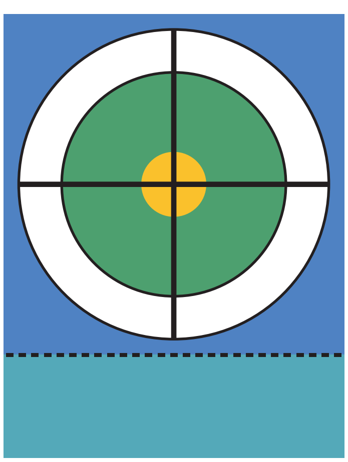
4. Place your protractor on the ground in front of you.

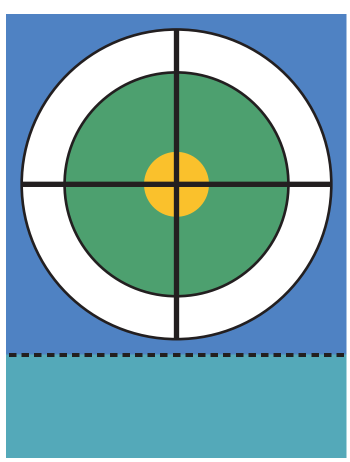
5. Tape your laser pointer to the swinging arm of the protractor. Make sure the laser pointer is lined up as straight as possible with the swinging arm.

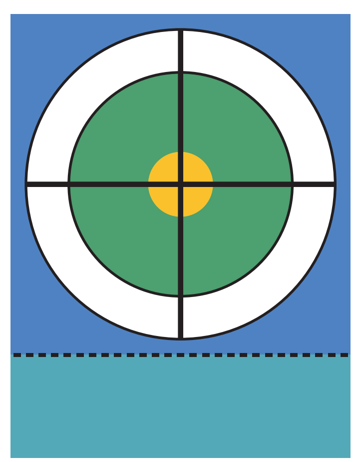
6. Turn the laser pointer on, and move the edge of the swinging arm of the protractor so that it lines up with ‘0’.

7. Adjust the protractor so that the laser hits the middle of your target.

8. Slowly and carefully pivot the laser to the left or right. How many degrees can you pivot your laser before you’re unable to hit the target? Read the result indicated by the protractor’s arm. The number you record should be very small—biathletes have to have superb aim to hit these tiny targets!







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Great job!

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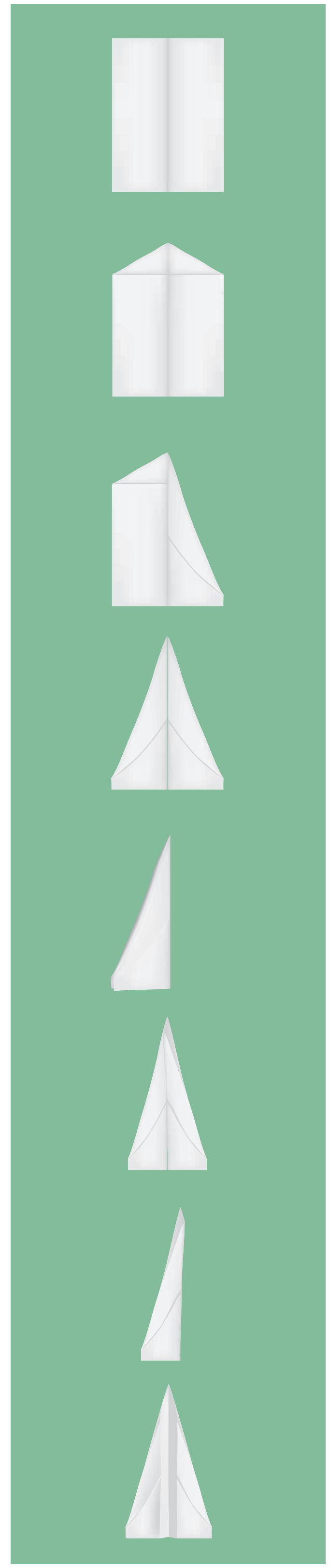
Answer Sheets

Ode to the Olympics: Winter Edition

Bobsled
Figure Skating
Ice Hockey
Snowboarding
Slalom Skiing
Downhill Skiing
Speed Skating

Answer Sheet

Winter Olympics
Bobsled



Try This!

Experiment with aerodynamics using a paper airplane made out of a sheet of 8.5 by 11 inch printer paper.

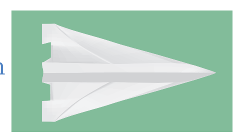
Think of the time when you're holding the airplane and winding up to send it sailing through the air as the push-off—for the plane to fly, the plane has to accelerate from rest just like the athletes must get the bobsled moving from rest at the starting line. Like the bobsledders during the push-off, you need to keep the motion of the plane straight and steady, or it'll crash right when you release it.

1. If the paper airplane is travelling fast and smoothly when you're holding it, it will continue to travel in the same way when you let it go. Practice throwing your airplane until you can get it to fly straight and steady several times in a row. Right now, your airplane is very aerodynamic.

2. Cut one-inch slits on each wing along the middle fold. Fold the two flaps upward so that they are at a 90 degree angle from the wing. Throw your modified plane several times.

How does the plane fly after you add the flaps? Does it fly as fast and far as before? Why?

The paper airplane floated more and did not go as fast when the flaps were added. This is because the flaps added drag to the airplane, making it less aerodynamic.



3. If an object has more **mass**, it also has more **inertia**. So when a massive body is in motion, forces of friction have less of an effect on its velocity. For this reason, bobsled teams want to maximize the amount of weight in the bobsled. The weight limit in the four-man bobsled is 630 kg (including athletes and sled). If the team doesn't reach that weight, they are allowed to add metal weights to the sled.

Add a paperclip to the nose of your airplane along the base fold. How does it fly? Why?

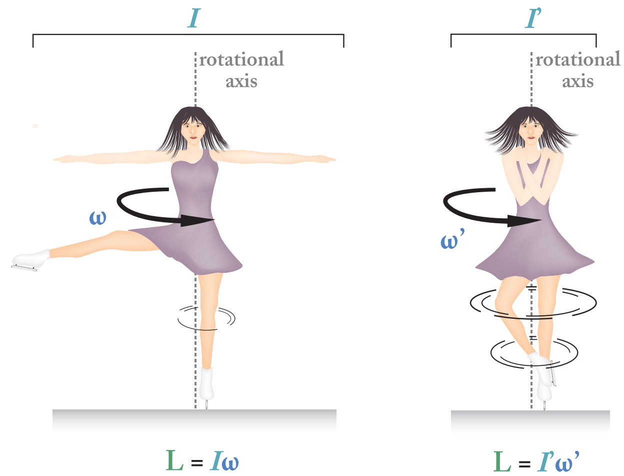
The airplane should fly faster, straighter, and steadier because the paperclip added mass — and inertia — to the airplane, making it more resistant to change in its motion and less affected by forces of friction like air resistance.

Answer Sheet

Winter Olympics
Figure Skating

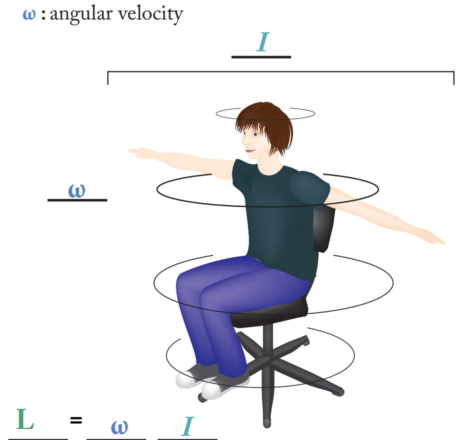
One of the figure skating moves that makes us "ooh" and "aah" is the spin, where the skater rotates in one spot at a dizzying speed. The skater starts the spin with her arms out, and when she tucks them into her body, she goes even faster.

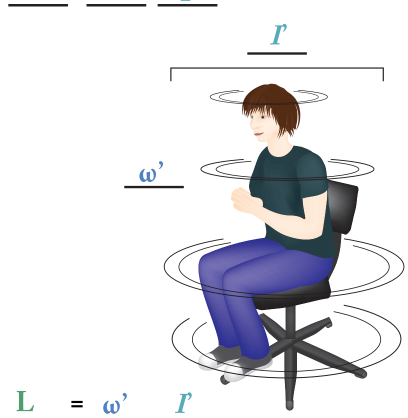
This is due to the law of **conservation of angular momentum**. It's harder to make a mass rotate around an **axis** that's far away than it is to make a mass rotate around an axis that's close. When a skater tucks her arms in, their mass is closer to the axis, so it's easier to rotate—this is called decreasing the **moment of inertia**. Because angular momentum is conserved, her rotation speed must then increase.



L : angular momentum
I : moment of inertia
ω : angular velocity

Label the diagram for the variables:
L : angular momentum
I : moment of inertia
ω : angular velocity





Try This!

1. Set a swiveling chair in an open room, making sure that while sitting in the chair with your arms and legs extended, you won't hit anything.

2. Sit in the chair and begin spinning by pushing off the floor with your foot. Fully extend your arms outward. Keep kicking until you get a good spinning velocity going.

3. Pull in your arms, holding them tightly to your chest. What happens? Why?

Explanation: The speed of rotation increases because of the law of conservation of angular momentum. This happens because the mass of your arms is closer to the rotational axis, decreasing the moment of inertia.

4. Extend your arms outward again. What happens now? Why?

Explanation: The speed of rotation decreases because the moment of inertia increases as the mass gets farther from the rotational axis.

→ You can repeat the experiment with light weights in your hands, like dumbbells or books, to see an even greater effect!

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Answer Sheet

Winter Olympics

Ice Hockey

Bending the stick against the ice is like compressing a spring. It packs the stick full of **potential energy.** Hockey sticks, like springs and rubber bands, are elastic objects, which means that they're flexible. When the hockey stick is in its usual position, which is straight, there's no stored energy. But the hockey stick can be bent some without breaking (this is called **deformation**), but when it's bent, it will try to go back to its normal position. When the stick strikes the puck, that potential energy turns into **kinetic energy**, sending the puck speeding away.

Try This!

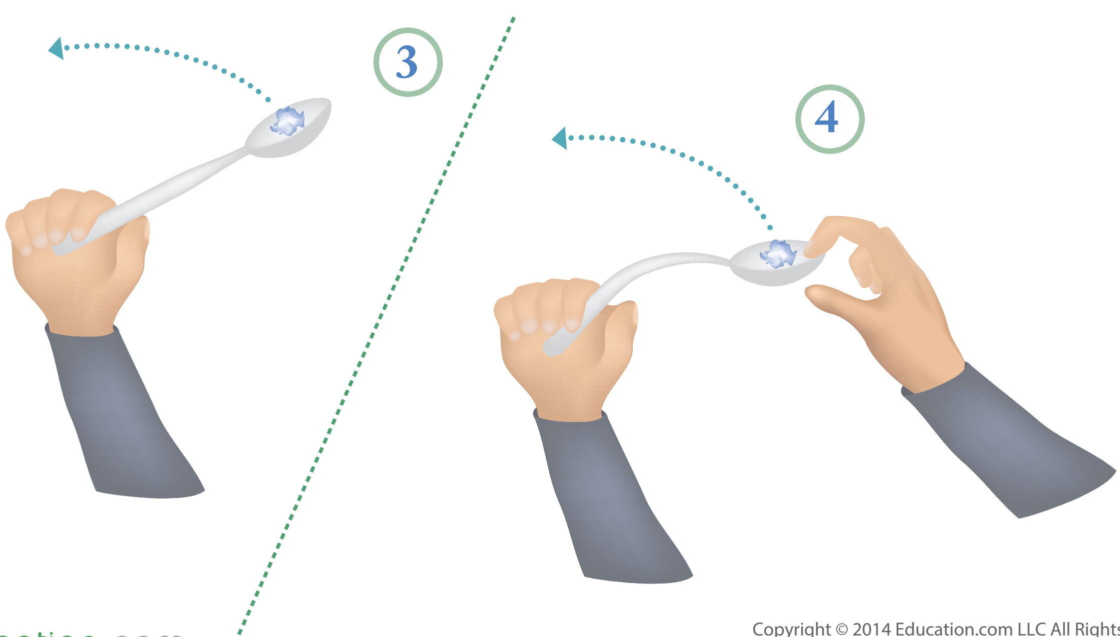
1. Get a plastic spoon that can bend about an inch backwards without breaking (biodegradable spoons tend to be more flexible than other plastic spoons).

2. Make a tight wad of paper about half an inch in diameter.

3. Hold the spoon from just the handle and load the wad onto the dip in spoon. Fling the spoon forward and observe how the wad travels through the air.

4. Now, do the same thing, only this time, pull back on the top of the spoon so that the handle bends. Release the spoon and observe how the wad travels through the air. How does this launch compare to the first? How can you explain this?

Explanation: When you bent the spoon, the wad travelled faster and farther through the air. Bending or deforming the spoon gave it more potential energy, which turned into more kinetic energy after you released the spoon.



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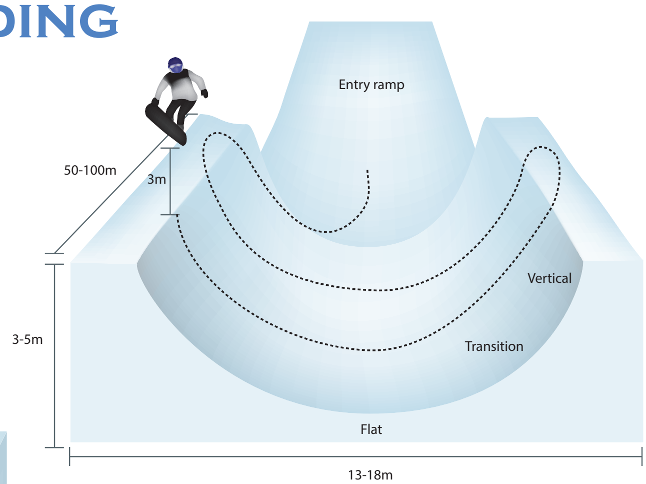
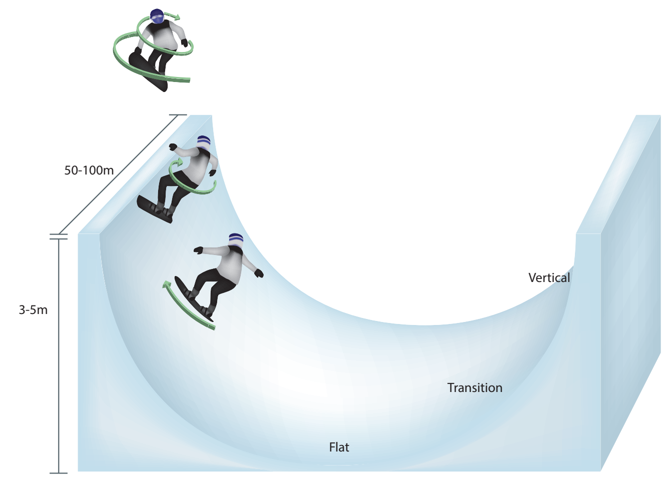
Answer Sheet

Winter Olympics
Snowboarding

In the snowboard half-pipe event, snowboarders use **velocity** and **torque** to perform tricks in the air.





A snowboarder creates **torque** by twisting his torso at the "vertical" of the half-pipe. This turns **linear momentum** into **angular momentum** as he rotates around his own vertical **axis**.

Try This!

1. Stand up in a clear area. Make sure that you have enough space to reach out both your arms and not touch anything.

2. With your feet about shoulder-width apart, jump straight up. Do this a few times. What kind of momentum is your body experiencing? In what direction?

Your body has linear momentum, in an upward direction (perpendicular to the ground).

3. You're going to jump again, only this time, twist by rotating your chest and shoulders left as you jump. What happened?

When you twisted your chest and shoulders in the air, your whole body rotated left. When you landed, you were facing a different direction from your starting position.

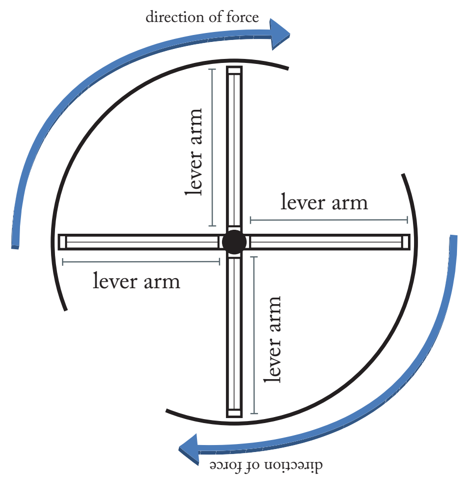
4. Explain how this happened using the terms **linear momentum, angular momentum, torque,** and **axis**.

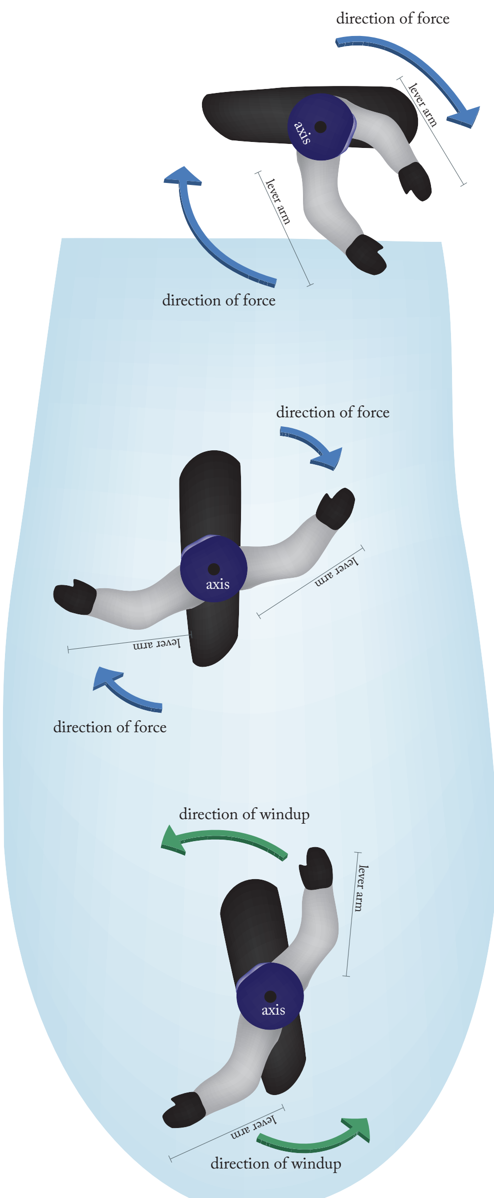
When you jumped and twisted your chest and shoulders, you created torque, which converted your linear momentum into angular momentum and caused you to rotate around your vertical axis.

Answer Sheet

Winter Olympics
Snowboarding

Before a snowboarder does a spin, he extends and "winds up" his arms. By doing this, he's increasing the length of his lever arm, making it easier for his body to rotate. Think about opening a revolving door—is it easier to open by pushing on the edge farthest from the hinge or closer to the hinge? When a snowboarder swings his arms, it increases torque, making it easier for the rest of his body to spin.





Stand in your original position. Without moving your feet, extend your arms away from your body. Point your right arm in front of you and your left arm behind. Your chest and shoulders should be rotated left. Now, as you jump, swing your arms clockwise. How did winding up your arms affect your spin?

Winding up your arms increased the length of the lever arm and created more torque, so it was easier for your body to spin.

Cool Fact:
If snowboarders maximize their torque on the half-pipe, they can spin up to 600° per second—that's nearly two full spins!

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Answer Sheet

Winter Olympics

Slalom Skiing

Newton's first law says that any moving object wants to continue moving in a straight line at a constant **velocity** (speed). The same is true of athletes on skis. But what happens during events like slalom skiing? Athletes have to complete many quick turns while remaining fast and stable. To do this, alpine skiers use their legs to push on the snow against the force of their own **momentum**—and the more momentum an athlete has, the harder she'll have to push. It isn't unusual for a skier to have to exert hundreds of pounds of force on the snow for several seconds in order to change direction.

So what is momentum, anyway? It's the product of **mass** (weight) and **velocity** (speed), and is represented by the following equation:

p = mv

Where:

- **p** = momentum
- **m** = mass
- **v** = velocity

If you're kind of stumped as to how this is all related, here's one way you can think about it. What's an easier thing to stop: a train moving at 30 miles per hour or a marble moving at 30 miles per hour? If you're a good catch, it's pretty easy to snatch the marble out of the air. But if you tried to grab a moving train, the train would just yank you right along with it! Why? The train has a lot more **mass**, meaning it has more **momentum** than the marble—even if their **velocities** are the same.

So what does this mean for skiers? A heavier skier may be able to accelerate faster, because his momentum helps him overcome forces like friction from the snow. Here's the problem, though—in order to turn or come to a full stop, he has to push a whole lot harder on the snow in order to fight against his own momentum!

Try This!

Have a look at the following pairs of moving objects. Which object has the greater momentum? To find out, multiply each object's mass and velocity and pick the larger number.

1. A 7 kg bowling ball traveling at 8 m/s or 0.15 kg baseball travel-ling at 46 m/s

The bowling ball. 56 kg m/s > 6.9 kg m/s

-

2. A 92 kg sprinter running at 9 m/s or a 63 kg cyclist on an 11 kg road bike traveling at 12 m/s

The bike + rider. 828 kg m/s < 888 kg m/s

3. A 72 kg alpine snowboarder traveling at 21 m/s or a 61 kg skier traveling at 24 m/s

The skier. 1512 kg m/s > 1464 kg m/s

Answer Sheet

Winter Olympics
Slalom Skiing

Check out the illustration above showing a slalom skier during various points of a turn. The red line represents the path that the skier travels in. But remember what Newton's second law says—objects don't naturally travel along curved paths! To complete a turn, a skier has to work hard to change the direction of his **momentum** (represented by the straight blue lines) by using his legs to exert a **force** against the snow with the edge of his skis. The force of the snow pushing back on the skis is represented by the green arrow. (This force has a special name. We'll talk about it more when we explore the physics behind speed skating!)

What else do you notice about the diagram above? Do you notice anything the athlete changes about his body positioning throughout the turn? Take note of his hands, torso, and knees. Why do you think he does this?

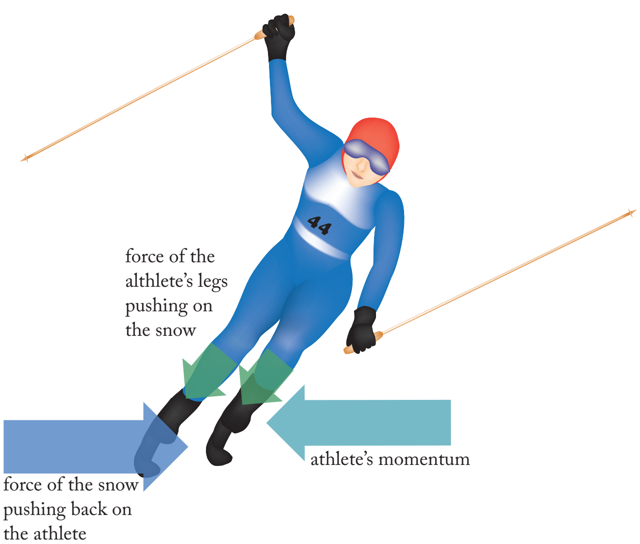
Explanation: He tucks his arms in front of his body to reduce drag. He leans to the inside of the turn so that he can dig the edges of both skis into the snow, which exerts the frictional force necessary to turn. He bends at the knee on one leg to get into a crouching position, which further reduces drag.

Answer Sheet

Winter Olympics
Downhill Skiing

Downhill Skiing is less technical than slalom skiing. It involves fewer turns, but athletes ski at much higher speeds. Most courses exceed speeds of 81 mph, and the French athlete Johan Clarey broke the 100 mph barrier on a particularly fast course in 2013.

Check out the diagram illustrating the various **forces** acting on the downhill skier below. She has just triumphantly crossed the finish line, but she's still moving pretty fast! She now has to **decelerate** (slow down) until her **momentum** returns to zero. See how she's turned her skis perpendicular to the direction of her momentum? She does this so that she can exert **force** on the snow with her legs. The snow pushes back with an equal and opposite force, which slows her down. But to come to a complete stop, how much force would she have to exert on the snow, and for how long? Let's find out.



We'll pretend this particular athlete has a **mass** of 62 kilograms, and she crosses the finish line at a **velocity** of 28 meters per second. First, multiply mass and velocity together to get her **momentum**:

62 Kilograms x 28 m/s = 1736 newton-seconds

The unit we use to measure momentum is **newton-seconds**. Newton-seconds tell us that the athlete's momentum really just comes from **force** measured in **newtons** (in this case, gravity) acting on her over a certain amount of **time**, measured in **seconds**. Gravity has given this athlete a momentum of **1736 newton-seconds**, so we know that she'll need to exert the same amount of force back on the snow in order to stop: **1736 newtons** (which is the same as **390 pounds**) if she wanted to come to a complete stop in one second. Crazy, right? Fortunately, skiers usually have more time to stop than that!

Try This!

How much force is in a newton? Think of it this way: weight is just a measure of how much force gravity exerts on something. There are just over four newtons to a pound. To lift a 5 pound dumbbell, you need to exert just over 22 newtons on it. Practice converting newtons to pounds using the following equation:

1 pound = 4.45 newtons

If a bowling ball weighs 2.2 pounds, it also weighs 9.79 newtons.

If your bike weighs 30 pounds, it also weighs 133.5 newtons.

If your textbook weighs 3 pounds, it also weighs 13.35 newtons.

If you weigh ______________ pounds, you also weigh ______________ newtons. (answers will vary)

Answer Sheet

Winter Olympics

Downhill Skiing

Try This!

Let's try to find out how much force each athlete would have to exert on the snow to come to a complete stop after crossing the finishing line.

 Soo-ho, an athlete from the Republic of Korea, skis over the finish line at a speed of 32 meters per second. She weighs 62 kilograms. How much momentum does she have?

62 kilograms x 32 meters per second =
1984 newton-seconds

To find out the average force Soo-ho would have to exert on the snow to stop in three seconds, divide the above result by three:

Soo-ho would have to exert an average force of 661.33 newtons on the snow to come to a complete stop in 3 seconds.

 Katja, an athlete from Germany, skis over the finish line at a speed of 35 meters per second. She weighs 64 kilograms. How much momentum does he have?

64kg x 35m/s =2240 newton-seconds.

To find out the average force Katja would have to exert on the snow to stop in three seconds, divide the above result by three:

Katja would have to exert an average force of 746.67newtons on the snow to come to a complete stop in 3 seconds.

 Sigmund, an athlete from Norway, skis over the finish line at a speed of 40 meters per second. He weighs 81 kilograms. How much momentum does he have?

81kg x 40m/s = 3240 newton-seconds

To find out the average force Sigmund would have to exert on the snow to stop in three seconds, divide the above result by three:

Sigmund would have to exert an average force of 1080 newtons on the snow to come to a complete stop in 3 seconds.

Challenge: Divide each result by 4.45 to find out the average force in pounds each athlete would need to exert on the snow to come to a complete stop in 3 seconds. Skiers need strong legs with lots of endurance, and it isn't unusual for some of the top skiers to be able to leg press 800 lbs!

Answer Sheet

Winter Olympics

Short Track Speed Skating

In short track speed skating, competitors race each other around an oval track at speeds of up to 40 miles per hour. How do speed skaters lean so sharply during turns without falling over? The athlete pictured below isn't supporting any of his weight on his left hand at all! Remember when we looked at how skiers push on the snow to turn? The force that pushes back is called **centripetal force** because it causes an object to move along a curved path instead of a straight one. Speed skaters turn using this same force, exerted by pushing against the ice with their skates.

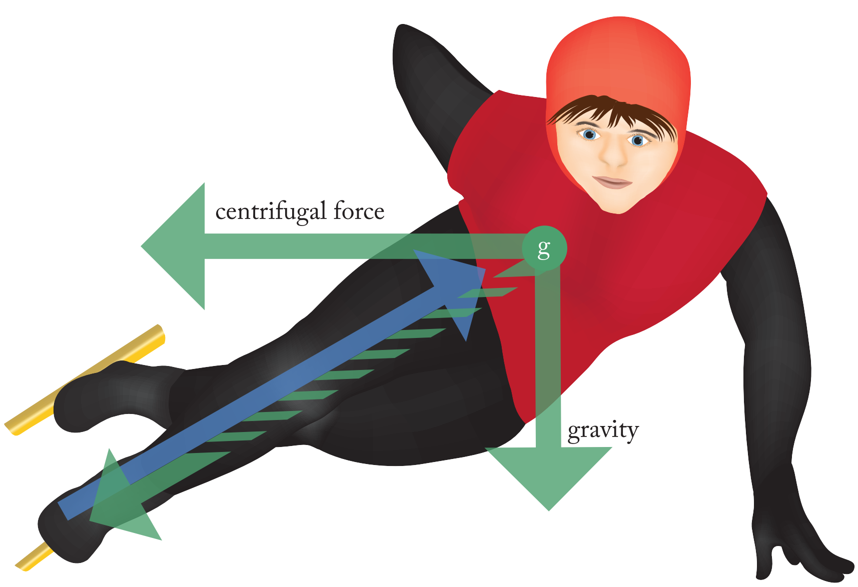
Centripetal force leads to an equal and opposite **centrifugal force**. Centrifugal force comes from **inertia**—the tendency of an already-moving object to want to continue moving in a straight line. As the skater turns, he has to work hard to fight against this tendency. Check out the diagram below:

Need an example of how inertia works? Think about braking really hard in a moving car. Your torso gets "thrown" forward into the seat belt, but this feeling just comes from the fact that your torso wants to keep moving, even though the car is stopping!

Here, we can think of gravity and centrifugal force adding up to one big diagonal force (the dashed green arrow) that pulls on the athlete's **center of gravity** (g). As long as the athlete uses his skates to push back up through the ice with an equal and opposite force (the blue arrow), he'll remain perfectly balanced during the turn.

Imagine you're riding as a passenger in a car. When the car makes a really sharp turn, why do you feel like you get yanked in the opposite direction? Use the explanation of centrifugal force provided to help you come up with your answer.

Explanation: Your body wants to continue moving straight ahead, but the the turning car attempts to pull your body in a new direction. Your body's inertia resists this pull, and you feel this resistance as an apparent force that "throws" you against the inside of the car door!



Answer Sheet

Winter Olympics
Short Track Speed Skating

Try This!

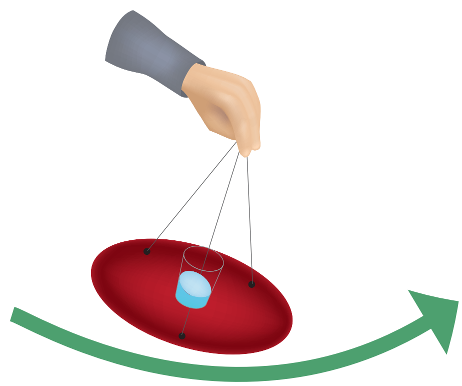
Get a feel for how centripetal and centrifugal forces work! Remember: centripetal force is a push or pull that causes an object to move in a curved path, but because objects have inertia, they resist this pull (remember--moving objects prefer to move in straight lines). We call this resistance centrifugal force.

Procedure

1. Use your permanent marker to mark three evenly spaced points along the edge of your frisbee.
2. Using the hot glue gun, attach one end of each length of fishing line or string to each marked point on the frisbee.
3. Place the plastic cup on the center of the frisbee. Don't glue it down.
4. Tie the loose ends of each string together in a knot.
5. Add about 2 inches of water to the cup. You can add a drop of food coloring if you want—this will make it easier to observe the level of the water as you conduct your experiment.
6. Hold the knot you made in step 4 between your thumb and forefinger.
7. Swing the apparatus back and forth, slowly increasing the velocity after each swing. Have a friend observe the level of the water. What happens?
8. Try swinging the apparatus so that the string is parallel to the ground. Why doesn't the water spill out? What's responsible for holding the water in the bottom of the cup?
9. If you're feeling particularly confident, try swinging the apparatus around in a complete circle. If you do it right, the water shouldn't spill out! How come?

Materials

- Three 16" lengths of string or fishing line
- Frisbee
- Hot glue gun
- Plastic cup
- Water
- Food Coloring (optional)
- Permanent marker



Record your observations below, and try to explain the behavior you saw. How can you compare what you observed to how a speed skater keeps his balance during a turn?

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(answers will vary)