Purpose

You have seen that when an object is already moving, a force acting on it in the same direction as its motion will make it speed up, while a force in the opposite direction to the motion will make it slow down. But what if the force is applied in a direction that is from the side with respect to the motion? What effect will such a force have?

For instance, what would happen to the motion of a spacecraft if it fired a small engine on its side while it was moving forward?

Collecting and Interpreting Evidence

Experiment #1: What happens if a moving object is tapped on the side?

You will need:

› Soccer ball (or similar)
› Stick (or some other object than can be used to tap the ball firmly)

**STEP 1:** Start the ball rolling across the floor by giving it a sharp tap with the stick. While it is moving, give it a second sharp tap, but this time at right angles to its direction of motion. (See picture below.) **Pay careful attention to both the speed and direction of the ball after this second tap.**
Note: It is very important to make sure that the strength of the sideways tap you apply to the ball is of about the same strength as the tap you used to start the ball moving in the first place.

On the diagram above, sketch the path of the ball, after the sideways tap.

After the sideways tap, is the ball’s motion in the same direction as before the tap, in the direction of the sideways tap itself, or somewhere in between the two? (If you are not sure, you may wish to repeat the experiment, making sure the strength of both the initial and sideways taps is close to the same.)

*It is somewhere in between the two.*

Why do you think the direction of the ball’s motion, after the sideways tap, is different from its original direction?

*The sideways tap made it change direction.*

Why do you think the direction of the ball’s motion, after the sideways tap, is different from the direction of the sideways tap itself?

*The ball was already moving to the right and it keeps on moving that way. The tap made it move upward as well, so after the tap it is moving both to the right and upward, which is more of a diagonal.*
In this experiment the direction of the ball’s motion changed as a result of the force exerted on the ball by the stick during the interaction between them.

Do you think a force is always needed to change the direction of motion of a moving object, or can the direction change on its own? Why, or why not? Give two other examples to illustrate your thinking.

Yes, I think a force is always needed to change the direction of a moving object. All changes in motion (speed or direction) need an outside cause. Other examples would be a soccer player kicking a moving soccer ball so it changes direction, or a hockey player hitting a sliding puck with his stick so as to redirect it.

**Experiment #2: Simulator Exploration.** What happens if a continuous sideways force acts on a moving object?

You will need:

- Access to the I&M computer simulator

**STEP 1:** As before, imagine that there is a soccer ball (or a ball of similar size and mass) rolling across the floor in front of you. At some point you give it a quick sideways tap that changes its direction, as shown below. A short time later you give it another sideways tap (relative to its new direction of motion).

Suppose you were to keep giving such sideways taps (always relative to the direction of motion at that time) at regular intervals, and always from the same side of the ball. What would the path of the ball look like in this case?

Sketch your idea on the picture to the right, showing the path of the ball and its position when the taps are applied.

Explain your reasoning.
Each tap will change the direction of the ball, making it turn in the same direction each time.

STEP 2: You can compare your ideas with those of scientists by using the I&M Simulator. Open the first set-up file for this homework assignment. You will see an object that is already moving toward the top of the screen (or will be when you run the simulation).

Note: as before, the red half-arrow is a speed-arrow for the ball, representing the speed and direction of its motion. Any forces acting on the object will be represented by black arrows, as in the other simulators.

Run the simulation and, while the object is moving, apply some sideways taps at regular intervals (using the spacebar on the keyboard) to try and make the object follow the octagonal path shown on the set-up.

Sketch the path, and indicate the points at which you had to give the object a tap to get it to follow that path.

Why do you think you had to apply a tap at those particular points?

To make it change direction at that point.

In between each pair of sideways taps, what is the path of the object like? Why do you think this is?

In between taps the path is straight, because there is no force to change the direction.

STEP 3: In the simulator, the taps are represented with black force arrows. Run the simulator again, and watch carefully the direction in which each tap is aimed.

Is each individual tap aimed in the object’s direction of motion before the tap, its new direction after the tap, or in a direction between the two?

The taps are aimed in a direction between the two.
Are all the taps aimed in the same direction, or is there some other simple way to describe how they are directed? (For example, is there some common point they are all aimed toward?)

They are all aimed toward the center of the octagon.

Now, suppose that, instead of quick taps, you were able to apply a continuous sideways force to the object as it moves.

What shape do you think its path would be then? Explain your reasoning.

The path would be a circle shape because the continuous force would make the direction change continuously.

**STEP 4:** To check your idea, open the second simulator set-up file for this homework assignment. This set-up shows an object that is initially moving diagonally up and to the right. (Note the direction of the speed arrow.) However, when the simulation is run, a continuous force will be applied that is always directed sideways with respect to the direction of motion.

Run the simulation, and sketch the path of the object below. Choose four points on the path and draw the object at those points, together with its speed arrow and an arrow representing the force acting on it at that point.

(Alternatively, if you are completing this homework assignment electronically, you can use the ‘snapshot’ tool in the simulator and then paste the pictures into this document.)
At any particular moment in time how would you describe the direction of motion of the object? Is it headed outward (away from the center of the circle), inward (toward the center of the circle), or at a tangent to the circle?

*The red speed arrows show the direction of motion. They always seem to be aimed at a tangent to the circle.*

What is the relationship between the direction of motion of the object and the direction of the force acting on it? Do they always point in the same direction, opposite directions, or are they related in some other way (you describe it)?

*The black force arrows always point toward the center of the circle, whereas the speed arrows are at a tangent to the circle. They always seem to be at right angles to each other. This makes sense as it is sideways forces that change the direction.*

Is there a common point toward which the force always points? If so, what is it?

*Yes, the force always points toward the center of the circle.*

What do you think would happen if, while the object was moving in its circular path, the ‘sideways’ force were to disappear? How do you think the motion of the object would change? Explain your reasoning.

*With no more force to change the direction, the object would then move in a straight line.*
You can remove the continuous sideways force by tapping on the spacebar in this set-up. Start the simulation running again, let it run for a few seconds, and then remove the force.

Sketch the path of the object, both before and after, you remove the sideways force. Again, choose some points on the path (both before and after you removed the force) and draw the object at those points, including its speed arrow and force arrow (if relevant).

Did the behavior of the object when the force was removed agree with your prediction above? If not, try to explain it.

Yes it agrees.
Two students in a previous class were discussing what happens to an object moving in a circle, when the force making it do so is removed.

I think that, since there is no longer a force to make it change direction, the object will move in a straight line, in the direction it was headed at the moment the force was removed.

I'm not so sure. I do think it will move in a straight line, but the direction will be the same as the direction of the last force that acted on it.

Samantha

Kristen

Who do you agree with (or neither), and why?

We agree with Samantha. The last force that acted on the object in the simulator pointed toward the center of the circle, but when the force was removed that's not the direction the object moved. Instead it moved at a tangent to the circle, which is where it was headed at that moment anyway.

Summarizing Questions

Write your own answers to these questions. Leave space to add any different ideas that may emerge when the whole class discusses their thinking.

S1: What effect does a sideways force have on the motion of an object? Does it seem to change the speed, as forward and backward forces do, or does it change some other aspect of the motion (or both)?

Definitely changes the direction. Hard to tell if the speed changes significantly.

S2: If a continuous sideways force acts on an object while it is moving, and always points toward one place, what will the object’s path be like?
It will move in a circle because the continuous force will change the direction continuously.

S3: If no sideways forces act on a moving object, what will its path be like? Explain your reasoning.

It will move in a straight line because there are no forces to change the direction.

S4: Imagine tying a stuffed toy to a string and swinging it around in a horizontal circle above your head at a constant speed. (A top view is shown here. The curved arrow simply indicated the direction of rotation.) Does a sideways force act on the toy? How do you know?

Yes, a ‘sideways’ force must act on the toy to keep changing its direction so that it moves in a circle.

What other object do you think is exerting this force on the toy?

The string is exerting the sideways force.

On the picture above, draw a speed arrow and an arrow representing the force acting on the toy.

S5: Now, suppose, after the toy has moved a bit further round the circle, the string were to break when the toy was in the position shown in this diagram. Draw a line on the diagram to show what the path of the toy would be after that happened. Explain your reasoning below.

The force that is changing its direction has gone, so it moves in a straight line in the direction it was headed when the string broke.
The nature of sideways forces

It is important to realize that the forces that cause objects to change direction (moving in a circular path is just a continuous change in direction) are the same as the forces that cause objects to speed up or slow down. For example, if your second tap in Experiment #1 had been in the same direction as the motion of the ball, then the ball would have sped up, rather than changed direction. If the tap had been in the opposite direction to the motion, it would have slowed down. The difference in effect was due to the direction in which the force was applied, relative to the motion, rather than anything different about the force itself.

This is true of all forces. For example, a hit from a hockey stick could be used to make a puck speed up, slow down and stop, or change direction, depending on how it is applied. Another example would be the force of gravity (which you will study in the next Chapter), which makes objects fall to the ground, but is also responsible for keeping the Moon in its (nearly) circular orbit around the Earth.

In the summarizing questions you considered a force exerted by a string (which scientists call a ‘tension’ force) that made a stuffed toy continuously change direction, and so move in a circular path. Describe, and sketch, two other situations, one in which the tension force in a string is being used to make an object speed up, the other in which the same force is being used to slow an object down.

*You could pull on a string attached to a sled on an icy surface. That would make it start to move and speed up.*

![Pulling force](image1)

*Once the sled is moving, you could also pull backwards on it with the string to make it slow and stop.*

![Pulling force](image2)