

Applying Newton's Third Law of Motion in the Gravitron Ride

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In this story, concepts including frictional force, centripetal force, centrifugal force, Newton's first law of motion, Newton's second law of motion, and Newton's third law of motion are elucidated through an exchange between two students enjoying an amusement park ride.

It is 1 p.m. Bobby and his friend Joe are at the amusement park. Bobby is an undergraduate student studying physics at his local community college. Joe is also a college student, majoring in English literature, and has never taken a course in physics before. Bobby is going to challenge Joe intellectually in his attempt to understand a ride called the Gravitron.

Bobby: Hey, Joe, look over there. The line for the Gravitron is short. Let's go on it.

Joe: Well, what does the ride do?

Bobby: It's a really fun ride. Basically, you stick to the wall of a spinning chamber while the floor drops out from under you.

Joe: That's impossible! No one can stick to a wall...unless they use glue on themselves!

Bobby: (*Bobby laughs.*) That's really funny. Nope, no glue or any other sticky stuff is used. You will stick to a wall.

Joe: Okay, Bobby...Let's see.

Bobby and Joe board the ride and enter a big circular room with rubber-padded walls. They stand up against the wall next to each other. Then the room begins to spin slowly, gradually spinning faster until they reach a high angular (or rotational) velocity. Just as Bobby promised, once they reach this high angular velocity, both boys stick to the wall so much that they can barely move. At that point, the floor below them drops about a half meter and both boys are now 50 centimeters above the floor as they stick to the wall. Eventually, the floor rises and the ride slows down. Once it stops spinning, the boys are able to freely move from the wall.

After the ride, Bobby and Joe go to a restaurant for lunch. While waiting for their food they talk about the ride they just went on:

Bobby: Well, I told you that we would stick to the wall.

Joe: I don't get it, why did we stick to that wall when the room spun?

Bobby: In order for you to understand why, I have to explain a few things to you. Are you up for learning some physics instead of your usual Shakespeare?

Joe: Absolutely, I really want to know what went on in that ride. It doesn't make sense to me. I really want to understand it.

Bobby: It's a bit complicated, so stick with me.

Joe: Okay Bobby, go ahead and explain.

Bobby: Well, first you have to understand the three vector definitions of motion.

Joe: What do you mean by “vector”?

Bobby: A vector quantity is a quantity that specifies not only a magnitude, which is basically a number, but also a direction, which is usually specified as an angle.

Joe: Oh, you mean like five meters northeast?

Bobby: Yes. That is an example of displacement where a position is measured with respect to an origin. Instead of saying northeast, we specify an angle between zero degrees (north) and 90 degrees (east). Now, velocity is also a vector quantity that is a measurement of how the displacement or location of an object changes with time, basically speed as in kilometers per hour, distance per unit time. Finally, acceleration is the rate of change of velocity with respect to time.

Joe: Okay. So what do these motion definitions have to do with me sticking to the wall?

Bobby: Well, what made you stick to a wall is a vector quantity called a force that is essentially a “push” or a “pull” on an object. Isaac Newton described the three fundamental laws of motion regarding forces in the 17th century. The first law states that if an object is not moving or moving with a constant velocity, then all of the forces exerted on the object (or the net force acting on the object) will add up to zero. The second law says that if an object’s velocity changes over time (accelerates or decelerates), the net force acting on the object will equal an object’s mass times the acceleration it is encountering.

Joe: So during the ride I was accelerating as the room spun faster and faster. Our speed increased.

Bobby: That’s right Joe.

Joe: But once the room reached full speed, we weren’t accelerating any more. There was velocity, but no acceleration. So why did we stick to the wall if there was no acceleration?

Bobby: I see why you’re confused, this is a complicated process. Velocity is a vector quantity so it doesn’t just have magnitude (speed), it also has direction. If an object’s direction is changing, then the velocity of the object is also changing. Since we were moving in a circle, our direction was always changing.

Joe: So, from one point in time to the next, we were always moving in a new direction as we spun around the circle—and, since we had been going in a different direction the instant before, we were accelerating into the new direction. I see. If you travel in a circle, you’re always accelerating even though you’re traveling at a constant speed.

Bobby: You’re right, Joe! This net force is one that causes an object to accelerate by changing its direction so that it stays in a circular path (see Figure 1). Without this acceleration, the object would just continue in a straight path tangential to the circular path (see Figure 2).

Joe: I get it. I was traveling in a circular path and the wall of the chamber resisted the force of my body against it, preventing me from flying out in a tangential path.

Bobby: Not exactly. According to Newton’s second law of motion, as long as there is an acceleration acting on an object (your

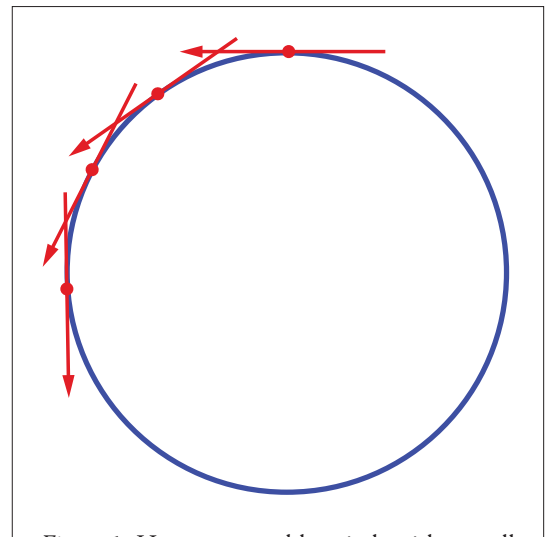


Figure 1. Here you see a blue circle with a small red circle representing an object traveling in a circular path around its perimeter. The red arrows represent the instantaneous direction of movement of the red circle as it travels in its circular path. As you can see, its direction is constantly changing so that its velocity is constantly adopting a new orientation, resulting in an effective acceleration as it travels at a constant speed since the velocity is always going from zero to something in every new direction. It is this acceleration that keeps the object moving in its circular path.

body), in this case caused by the change in direction, there is a net force acting on the object. In the Gravitron, the net force is generated by the wall of the spinning room that caused you to follow the circular path. The vector quantity of this net force is directed towards the center of the chamber. Since this net force is directed towards the center of the circle, it is defined as centripetal force.

Joe: Okay, now I'm confused. If the force was directing me towards the center of the circle, why did I stick to the wall? It felt like I was being pressed against the wall, towards the outside of the circle. You still haven't explained why we stuck to the wall.

Bobby: Many people have the misconception that there is an outward "centrifugal force" that acts on them and causes them to stick to the wall. However, that theory is totally wrong. Newton's third law of motion states that if one object exerts a force on another object then the second object will exert an equal and opposite force on the first object. Newton calls these two forces "action" and "reaction" forces, respectively. You've probably heard people say that for every action there is an equal and opposite reaction—that's true.

Joe: Oh I think I get it. So the wall is exerting a force on my body, making me move into the circle, but my body is exerting an equal and opposite force on the wall so the result is that my body doesn't move with respect to the wall at all, I stick to it!

Bobby: See, I told you you'd get it! Just try to think about it a little more like a physicist. Your body isn't moving towards the center of the circle, but the net acceleration is towards the center—if you think about it, you're not moving, you're stuck to the wall. The wall is exerting an action force on your body, and your body is exerting a reaction force against the wall. Essentially just what you said, but phrased the way a physics teacher would say it.

Questions

1. What is a vector quantity?
2. What are displacement, velocity, and acceleration, and what are their relationships to each other in terms of motion?
3. What are Newton's three laws of motion? Give an example of how the first two laws of motion describe the motion of an object.
4. Why is there always acceleration when an object travels in a circular path at a constant velocity?
5. What is centripetal force? (Use Newton's second law to explain.)
6. What is the force that causes an object to remain on a wall while the wall is spinning? (Use Newton's third law to explain.)
7. Explain why an object will stick to the wall with a greater force as the wall spins faster.



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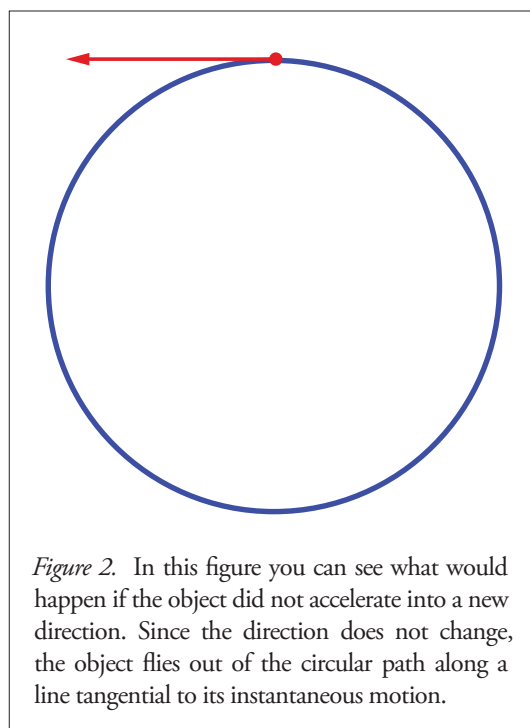


Figure 2. In this figure you can see what would happen if the object did not accelerate into a new direction. Since the direction does not change, the object flies out of the circular path along a line tangential to its instantaneous motion.