ARBOR SCIENTIFIC

Gyroscope Wheel

93-3501

INSTRUCTIONAL GUIDE

Contents

Gyroscope Wheel:

- Arbor Scientific Gyroscope Wheel
- 4 adjustable masses with screws and washers
- Pull cord
- Bungee cord
- 2 easy-grip handles with holes for precession demos
- 4 mm hex key for adjusting masses

Recommended for Activity:

- **Rotating Platform (P3-3510)**

Introduction

Gyroscopic behavior is one of the most engaging topics covered in physics. Students will be surprised and amazed by how much a gyroscope in motion tends to stay in motion in its spinning orientation. This is an example of angular momentum, which is itself an example of the law of inertia (Newton's 1st Law). Just by holding and manipulating a spinning gyroscope you get a feel for how much motion there is in an apparently stationary object.

Gyroscopic precession is a fascinating demonstration that should be included in every physics mechanics course. When a spinning gyroscope is only supported on one side, it does not simply fall over, but instead starts to rotate in a slow cycle called precession, like a wobbling top. The surprising effect is hard to predict, both in terms of how to control the precession's slow rate and in which direction it will rotate. With the use of a Gyroscope Wheel, these demonstrations, which were previously done by the teacher alone, can now be shared with the entire class.

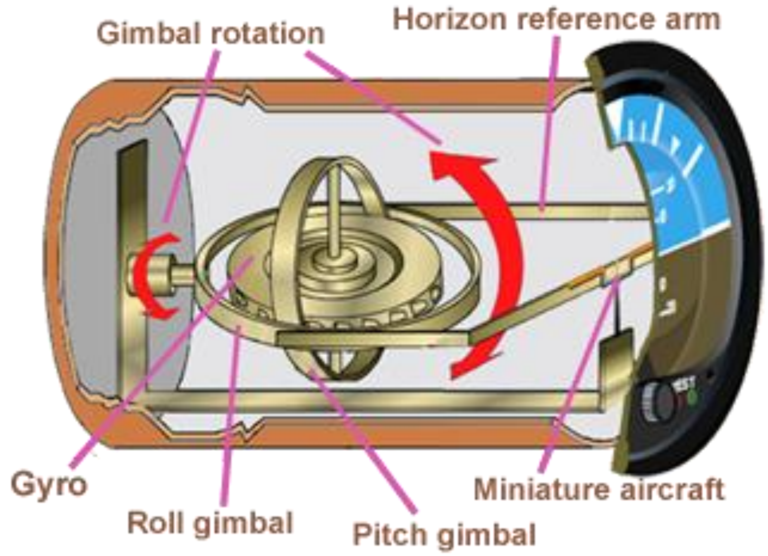
The conservation of angular momentum is easily demonstrated by the Gyroscope Wheel. For example, by standing on a rotating platform and inverting the spin direction, you will set yourself into rotational motion. The original angular momentum of the gyroscope is now put into your own body's rotation. However, the total angular momentum is conserved.

Safer, Modern Design

This particular gyroscope is adept at both demonstrating precession and allowing you to share the role of demonstrator with students. It is both light and simple in its appearance, which minimizes distractions. It is simply a gyroscope that demonstrates gyroscopic behavior. Because the Gyroscope Wheel is a smooth continuous disk, there is little risk of fingers or long hair getting caught in spokes like a bicycle wheel. The easy-grip handle helps keep the spinning wheel in hand. Also, the apparatus has low-friction bearings which make it easier to perform demonstrations for a longer period of time, without the need to restart the rotation multiple times. Additionally, the weights are adjustable and can be removed, this allows for qualitative and quantitative investigations of how inertia affects precession rates and other gyroscopic behaviors. For example, the dark stripe on the apparatus allows you to easily count the rotation rate (such as in a video) if you wish to measure the frequency of rotation, which is a topic that will be discussed later.

Applications of Gyroscopes

Gyroscopes are frequently employed in guidance systems. It is the default nature of a spinning object to maintain it spinning direction, and this is how pilots flying blind in poor conditions can safely steer the plane. Such gyroscopic guidance devices are referred to as “attitude gauges.” Another term for a gyroscope in this context would be a gimbal, which more specifically refers to the apparatus that holds the gyroscope and allows it to rotate freely, often in three different directions.



Gyroscopic effects can also be used to provide stability to objects that are meant to *not* change direction. A familiar example of this is the frisbee. The frisbee is spun so that it does not flip during flight. This allows it to cut through the air without incurring more air resistance. Also, it helps it maintain a "wing up" orientation, which allows Bernoulli effects to provide lift. Another familiar example is spiraling a football, which keeps it pointed through the air, like a bullet, to minimize drag.

Demonstrations

Part 1 – Feeling the Spin

Once a gyroscope starts spinning, it keeps spinning. That's angular momentum: an object in motion, remains in motion. In this case rotating. There are two ways to get the gyroscope spinning, one is to grab the wheel with one hand, hold the handle with the other, and pulling strongly down on its top, rotating it. The other method is to loop the string around the wheel's axle and pull on the ball while a partner holds both handles.

Now with the wheel spinning you can investigate its rotational momentum. By simply holding the spinning wheel and trying to turn it, you will readily feel the resistance it has to changing its motion. This is because to change the direction of the spin requires that you cancel out all the spin it already has, then add back all that spin in a new direction. This requires effort.

Part 2 – Angular Momentum is Conserved

When you get the gyroscope spinning, you can use it to show that angular momentum is conserved. This is most easily achieved by standing on a rotating platform while the gyroscope is spinning. Hold the gyroscope as it spins in a horizontal plane parallel to the floor. Stand on the platform and invert the gyroscope. This inversion will maximize the change in the gyroscope's angular momentum. But, by Newton's 3rd Law, you will now begin to spin. By taking the action of canceling the gyroscope's angular momentum, you have received it. Your action was met with an equal and opposite reaction.

Part 3 – Demonstrating Precession

Now we wish to demonstrate precession of the gyroscope. The first thing to do is to remind your students of what happens to the hanging wheel when it is allowed to hang with one support while NOT spinning. It just falls right over. But when we repeat this with the wheel in full spin, it does not fall over. Instead, it begins to precess in a circle slowly while staying upright. There is still torque on the system, however. Explain that this comes from the weight of the wheel itself pulling down at a lever distance from the point at which the string is attached (pivot).

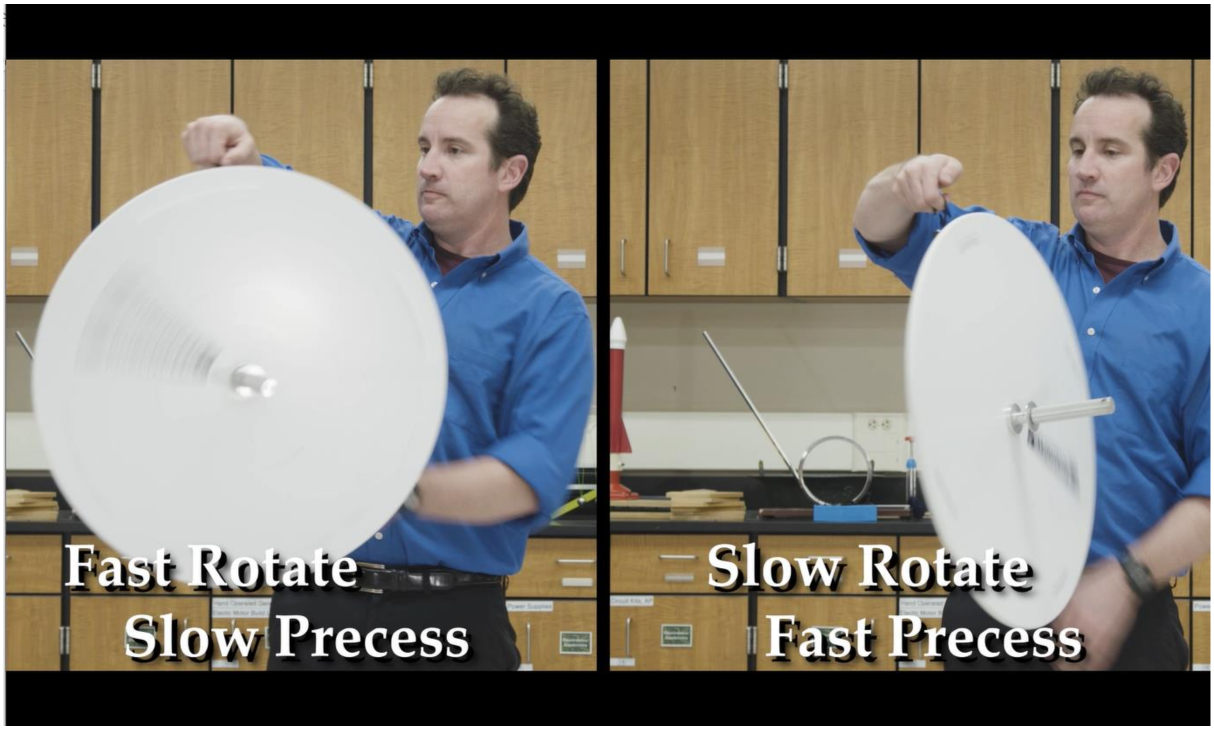
It is helpful to get the wheel spinning as fast as possible, this will help the precession to not decay into a diagonal – falling over – orientation. Second, point out that the frequency rate of precession is much lower than the frequency rate of the spin.

This might be a good opportunity to use some familiar language. Say, "a torque perpendicular to rotation will change direction but not angular speed. Does that sound familiar? Yes! That is a description of circular motion, but this time for rotating objects. In the case of centripetal forces, we say "a force perpendicular to velocity will change direction but not speed." In this case, we are describing rotations and torques rather than velocities and forces, but the result is the same. The torque on the gyroscope is applied perpendicular to the spin axis, thereby causing rotation. It does NOT increase or decrease the rate of spin.

Part 4 – Investigating Precession

Precession can be one of the most confusing topics to explain, so let's look at it closely through experiments and investigations. First, we acknowledge that the direction of spin determines the direction of precession. Demonstrate that spinning the wheel backwards will cause the precession to also reverse.

We also notice that the rate of spin controls the rate of precession, you can easily see this with the black stripe. The faster you spin the wheel, the slower the wheel will precess. This is the same effect that you feel in your hands when the wheel is spinning. The challenge to change its orientation is increased when the spin rate is higher.



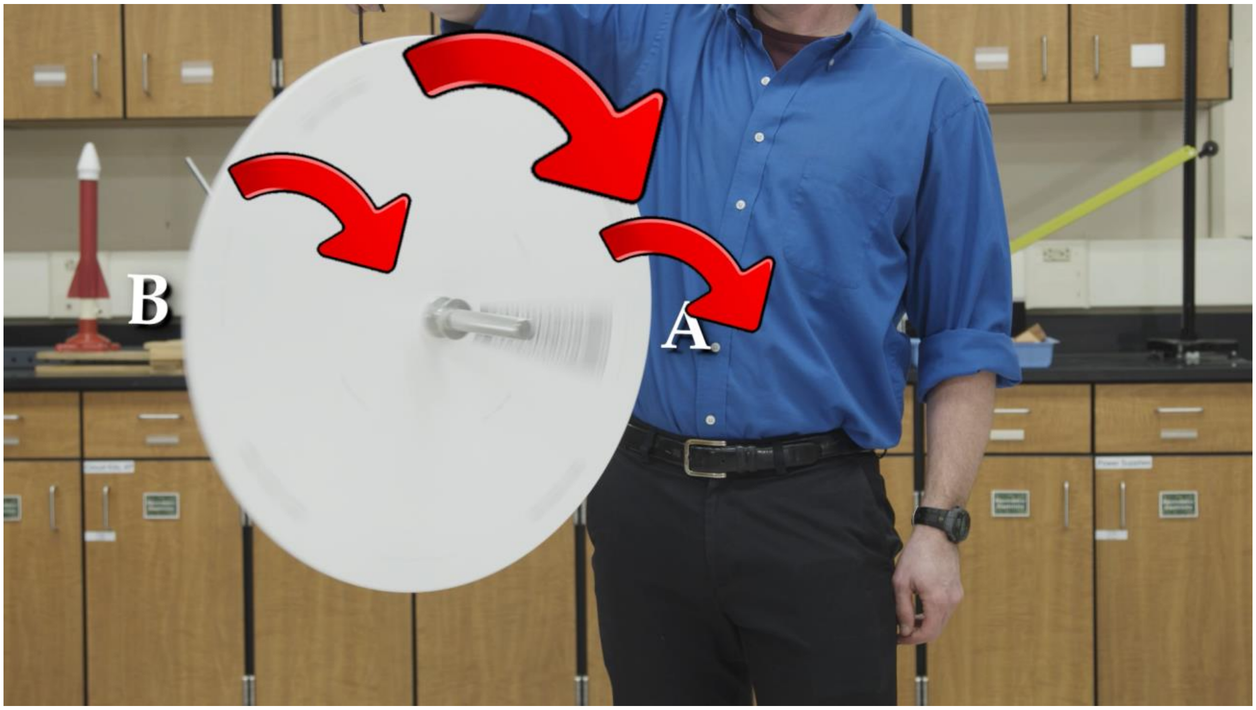
Next, we also note that the location of where the string attaches can affect the rate of precession. This is because the torque from the weight acting on the handle is dependent on the distance. Demonstrate this by moving the hook nearer to the axis. Now the wheel will almost not precess at all. This teaches us that it really is torque that causes the precession.

Lastly, we note that if we reduce the inertia of the gyroscope by moving the weights inward or reduce the mass of the gyroscope by removing the weights, that it will now precresses much faster. All these data help us to build up a formula. Note that spin has direction.

$$\textbf{Precession Rate (Hz)} = \frac{\underline{\textbf{Torque from weight}}}{\textbf{Spin * Inertia}}$$

Part 5 – Explaining Precession as a Consequence of Acceleration

Challenge yourself and your students to predict the direction of precession if you change the direction of spin or place the hook on the other side of the apparatus. This is a fair challenge for even the best physics student!



We imagine a point of the wheel that moves from A to B in the figure above. As it moves it is subject to the tipping torque from the wheel itself which wants to flop forward under its own weight. This torque accelerates the point to the right. But it takes time to get faster. Thus, when we finally get from A all the way to B we are now ready to move to the right, which is exactly what happens. Point B moves to the right and point A moves to the left. Try it for yourself!