18730 Gyro Studies

Purpose:

This product provides a rotary motion suite of products that include a versatile lab stool, built in turntable, bicycle wheel gyroscope, bag toss masses and two accelerometers along with a rotary arm for mounting them. This collection is aligned with the notion that "...I will throw your body in first and bring your mind in later." Angular momentum, gyroscopic stability and precession as well as important notions of conservation become all the more accessible, given this concrete mode of inquiry.

Contents and Components:

Bicycle Wheel Gyroscope (#18700)

One (1) Gyroscope Wheel
One (1) Handle Shaft
Two (2) Handle Grips
Two (2) Finger Guards
Two (2) Split Rings

Slip a finger guard over the handle shaft so that it rests against the grip already in place. Slip the shaft into the wheel bearing. Place the last finger guard over the shaft. Finally, use soap and water to lubricate the remaining grip and the shaft end. Then push the last grip on tightly to hold everything in place. Install the second split ring.

Versatile Lab Stool (18725)

One (1) Turntable Stool Top & insert plugs
One (1) 3-Part unassembled Stool
Two (2) Dowel Pins for step

Initial assembly requires mating the two large slotted pieces, pounding them with a soft mallet or the palm of the hand, before securing them by inserting the prongs of the step. The hole in the step prongs should face upward. Dowels secure the step in place. The assembly can be made permanent by gluing the pieces and gluing the Turntable top to the rest of the apparatus.

Gyro Studies Accessories:

One	(1)	Rotary Mounting Arm
Two	(2)	Bag toss Masses
Two	(2)	Accelerometers (#10-100)

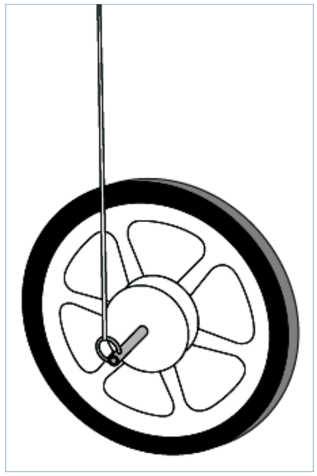
Additional useful materials:

support stand, one meter of heavy cord
assorted weights and weight hanger
stopwatch, optional motorized spinner

Preliminary Discussion:

The Turntable Top is designed to provide a low friction rotating surface to demonstrate experiments involving the conservation of angular momentum and rotational kinetic energy. It is capable of supporting one student, when placed on the assembled stool. The load should be uniformly centered to prevent the bearing from binding. The bearing should be kept free from debris, and can be periodically cleaned with a vacuum or high pressure air hose.

Initial Experiments:



A student sitting on the turntable top can have a bag toss mass in each hand to demonstrate how angular momentum is conserved with the arms extended and with the arms withdrawn. A bag toss mass can be caught or tossed by a properly balanced student to demonstrate the interplay between linear motion and rotary motion.

Experiments with gyroscopic precession and torque can be investigated using the included bicycle wheel gyroscope. Other experiments and demonstrations will be described, such as the accelerometers on the mounting arm or <u>other locally devised things that can be attached to the extra accessory mounting plugs and placed on the stool top.</u>

More Gyro Details:

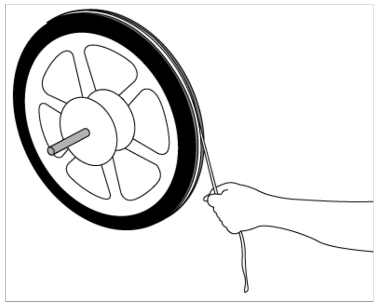
Gyroscopic precession is perhaps the most popular demonstration presented with the bicycle wheel gyroscope. This illustrates several principles of rotational motion and inertia. When a gyroscope is spinning about its axis, it has an angular momentum of:

$L = I\,\omega$

When the gyroscope is set spinning and is then supported horizontally from one end of its shaft, a steady circular motion of the shaft in the horizontal plane results. This is an interesting phenomenon for intuition suggests that the free end of the gyroscope axis should drop in a vertical plane toward the ground.

Consider the forces acting on the gyroscope. In such a configuration, weight is acting down-ward at it's center of gravity, and the upward normal force is acting at the pivot point. The wheel's weight thus produces a torque which in turn produces a change in the angular momentum of the spinning wheel. This change in angular momentum shows up as a change in the direction of the angular momentum vector. The rate of change of the direction of this angular momentum vector is given by: $\Omega = \Gamma / L$

where Γ is the torque on the gyroscope and L is its angular momentum. Notice that the angular velocity of the precession is proportional to the torque and inversely proportional to the angular momentum.



The rate of precession, Ω, can be tested by changing the torque applied to the gyroscope. This is accomplished by spinning the wheel up to the same speed for each test, then hanging it from a support stand by a cord through either split ring. Then, hanging a weight from the other split ring, time the rate of precession. Repeat the experiment using a larger weight. This procedure can be repeated for as many data points at necessary to illustrate the linear relationship between Ω and Γ.

The dependance of Ω on the angular momentum L, can be illustrated by spinning the gyroscope up to several different angular velocities. The angular momentum is proportional to the angular velocity ($L=I\omega$). Time the rate of precession for several different values of angular momentum (speed of the wheel). The resulting data will illustrate the inverse relation between Ω, the rate of precession, and L, the angular momentum. (The slower the wheel spins, the faster the rate of precession).

The gyroscope wheel can also be suspended from a string with its axis in a vertical direction. The resulting "gyroscopic pendulum" can be spun, then set swinging. The resulting motion of the gyroscope provides an interesting observation of torque and precession.

The gyroscope can also be hand held. When the handles are forced to one side or another, the resulting resistance to this motion (rotational inertia) provides a dramatic
illustration of the use of gyroscopes as stabilizers and navigation devices.

Conservation of angular momentum can be vividly demonstrated if the demonstrator, or student, sits on the turntable of the lab stool, while attempting to turn the gyroscope. Assume the student begins with the wheel's angular momentum vector pointing upward (the wheel would be rotating counter clockwise as seen from the top.) The student's angular momentum is zero (the student is not rotating). When the wheel is inverted by the student sitting on the turntable, (s)he will begin to turn in a clockwise fashion. This rotation is induced to compensate for the change in the angular momentum of the wheel (whose angular momentum vector now points downward).

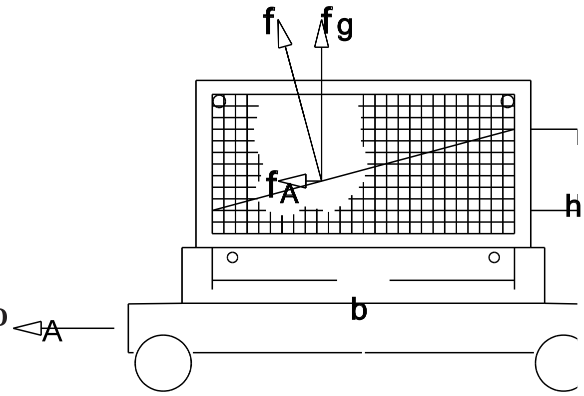
If one adds the angular momentum vectors of the student and wheel both before and after the wheel was inverted, one finds that this net angular momentum remains the same! Angular momentum is conserved. It is instructive to hand the rapidly spinning wheel back and forth between the subject sitting on the turntable and another person, inverting the axle each time.

Accelerometer Details:

Preparation:

Before mounting each accelerometer on the rotating arm, begin by unscrewing the two screws located on the side of the plastic chamber

near its top. The accelerometer can be filled by holding it under a slowly streaming faucet or by pipetting water into one of the holes. Fill the chamber half full so that the water level comes up to the zero line on the grid when held upright, level and at rest. Coloring the water slightly with food coloring will make the accelerometer easier to see when in motion. Screw the two screws back into place and mount the plastic chamber on the aluminum arm, using the thumbscrews provided. Two arrangements will be of interest. One matches the view in the illustration where one chamber is mounted at the extreme end of the aluminum channel and the other is right next to it. The other will be made by releasing the thumbscrews holding the innermost chamber and sliding it until it is centered on the turntable top of the lab stool. In this position, only one thumbscrew is needed to secure the chamber.
MAKE CERTAIN THE COUNTERWEIGHT IS SECURELY ATTACHED TO THE ALUMINUM CHANNEL



Background Information:

The liquid surface accelerometer is a hollow, flat, plastic container, partially filled with colored liquid (try a little food coloring in water). One face of the accelerometer is marked with a centimeter grid to accurately record the position of the liquid surface.

When the accelerometer is not being accelerated, the liquid surface is horizontal. But when it is accelerated toward the left with a constant acceleration "a" then the surface has a measurable slope. The liquid level rises a distance "h" at one end of the accelerometer and drops by an equal amount at the other end. The greater the acceleration, the steeper the slope of the water's surface. This allows us to measure the magnitude of the uniform acceleration.
There is a simple relation that expresses the acceleration in terms of the slope of the water's surface. This is: Slope = h/b = a/**g**

Where:
h is the difference in height from one end of the slope to the other.
b is the length of the accelerometer grid
g is the acceleration due to gravity

To find acceleration, multiply the slope (h/b) by **g**.

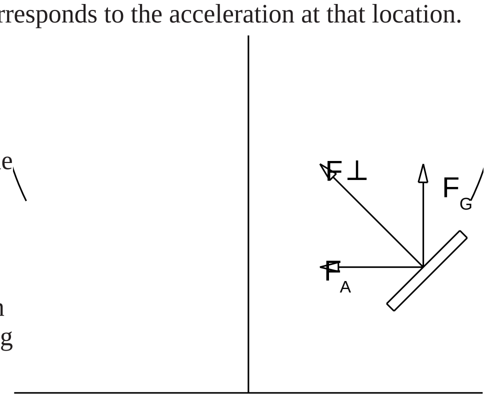
Put very simply, the steeper the water surface, the greater the acceleration. And the “wedge of water” is pointing in the direction of the acceleration. If the surface makes a straight line, all parts of the water are experiencing the same acceleration. If the water surface is curved, all parts of the water are experiencing a different acceleration and the local slope corresponds to the acceleration at that location.

Now, Finally the Accelerometer on the Turntable:

The innermost accelerometer must be carefully centered and secured on the turntable. For a constant rate of rotation the centripetal acceleration is proportional to the distance **R** from the center of rotation, that is

$$a = \omega 2R$$

where ω depends on the rate of rotation. Consider the boundary condition of R=0; this corresponds to a point directly over the center of rotation. If R=0 then the radial acceleration a will also be zero and gravitational acceleration is the only component of acceleration acting on that point. As **R** increases the radial component of acceleration increases, and the slope will also increase.



What happens when the pair of accelerometers are rotating together is generally a surprise to most persons. The arrangement of the mounting arm provides an opportunity to study all the possibilities for positions of the inner accelerometer, leaving the outer one in place both as a reference and to provide the necessary balance. The study should include various rates of rotation of the turntable, noting that the angular velocity is always the same for both accelerometers. With suitable equipment, it is possible to photograph the spinning accelerometers to provide numerical data directly from the screened grid on the chambers.

The serious investigator might seek to more directly mount a single accelerometer centered on the turntable. For this purpose and for other investigations sparked by individual curiosity, an extra accessory mounting plug is provided that fits the square hole in the turntable in the same way as the rotating mounting arm does.

The curve of the spinning liquid surface is described by a parabola with its apex directly over the center of rotation. Can you plot enough points from the accelerometer's grid to confirm the parabolic shape? How does this shape change with varying rotational velocities? The changing slope cannot be calculated directly from the accelerometer's scale as in the case of a constant slope **h/b**, but the slope can be found by an indirect procedure. Carefully observe the curved surface for a particular rotational velocity. Draw several points on a sheet of graph that correspond to points observed on the accelerometer then draw a smooth curve through these points. Pick a point on your curve a distance **R** from the center of rotation (the bottom of the curve) then draw a straight line through that point tangent to the curve. You can now measure the slope of this line graphically to determine the acceleration at that point.

Statement of the Theory:

Even when there is no acceleration, there still are two forces in balance on each drop of liquid. Acting internally, there is the drop's weight, and acting externally there is the balancing lift on the drop provided by the surrounding liquid. A still surface is always perpendicular to the direction of the balanced forces because if the liquid were too high on one side, the extra weight on that side would cause liquid to flow toward the low side.

Extension Activities:

Having established the parabolic surface for rotary motion, it is instructive to change the position of the accelerometer with respect to the center of rotation. This is the reason for providing the mounting arm and two accelerometers. Alternatively, a single accelerometer can be held with arms outstretched by a student who is seated on the spinning turntable. The student can then change at will the distance the accelerometer is removed from the axis of rotation, holding the device either along a radius or at right angles with respect to the radius during uniform rotation of the stool top. An adroit student may be able to hold accelerometers in both positions at the same time, since two are provided and they might be temporarily taped together if need be.

Time Allocation:

To prepare this product for the first experimental trial should take less than twenty minutes. Actual experiments will vary with needs of students and the method of instruction, but many are easily concluded within one class period. The user will decide whether to glue the components of the lab stool so that it can serve other purposes without losing parts, or to take it apart each time and store it away with the other components.

Feedback:

If you have a question, a comment, or a suggestion that would improve this product, you may call our toll free number.