Title Precession

AP Physics C Mechanics Objectives:

E.4.a.1 Students should be able to use the vector product and the right-hand rule, so they can calculate the torque of a specified force about an arbitrary origin.

E.4.a.3 Students should be able to use the vector product and the right-hand rule so they can calculate the angular momentum vector for a rotating rigid object in simple cases where this vector lies parallel to the angular velocity vector.

F.1.j Students should understand simple harmonic motion, so they can develop a qualitative understanding of resonance so they can identify situations in which a system will resonate in response to a sinusoidal external force.

Objective(s)

1) Students will graphically and mathematically determine the relationship between the precession rate and the angular momentum of an acrylic rotating sphere.
2) Students will graphically and mathematically determine the relationship between the precession rate and the external torque on an acrylic rotating sphere.

Essential Questions

1) What is the relationship between the precession frequency of a bike tire and the spin rate of the tire?
2) What is the relationship between the precession frequency of a bike tire and the torque caused by gravity on the tire?

Materials

- Bike tire for review of angular momentum, torque and rotational inertia and also to introduce the phenomena of precession.
- NMR apparatus & stop watch to time precession period

Safety

Take care to keep loose clothing and hair away from the spinning wheel.

Technology

- Students will be collecting data using computers and graphing data in Excel.

Activity (90 mins)

Engage: Bike tire demo

Time	Description
15 min	Use a spinning bike tire to demonstrate how an external torque results in a change in the direction of the angular momentum vector as given by the right hand rule. Pick a student volunteer to try to hold the axle of a non-spinning bike tire at one end horizontally and then discuss why this is not possible. Now pick another volunteer to perform the same task but with a spinning tire. Students will note that the spinning tire can be held horizontally while the non-spinning tire cannot. Then review the relationships of $\vec{F} = \frac{d\vec{p}}{dt}$, angular momentum, torque and rotational inertia. Have students help derive the angular equivalent of $\vec{F} = \frac{d\vec{p}}{dt}$ and have them notice the relationship between the direction of precession and the direction of spin and the direction of precession and direction of torque. Use this to introduce the right-hand-rule. Also qualitatively explore with students the possibility that there might be a relationship between the precession rate and torque and between precession rate and angular momentum. Use this discussion to introduce the forthcoming investigation. Show and describe how the apparatus works and how students can collect data from the apparatus.

Explore: NMR Lab	
Time	Description
45 min	Purpose: To graphically and mathematically model the relationship between the precession rate, ω_p, and . . . a) $\left\|\vec{L}\right\|$ b) $\left\|\vec{\tau}_{ext}\right\|$ For part (a) students need to first determine the rotational inertia of the sphere about its diameter through the axis of the internal magnet. Students will need to vary the angular velocity of the sphere to get at least six different angular momenta measures and corresponding precession frequencies. Students should be reminded about getting a good spread in data and discuss methods of doing that (i.e. find the slowest and fastest speeds measureable). For part (b) students will vary the external torque by varying the current through the Helmholtz coils. Since these students are not aware of the relationship between conventional current and the magnetic force, students should be shown that another permanent magnet causes the ball to precess. Students should concluded that this is due to an external force of magnetism exerting an external torque on the spinning ball. Then discuss the uncertainties related to using the permanent magnet in this way and prompt for alternatives that might reduce the uncertainty. At this time introduce the use of the Helmholtz coils and demonstrate the linear relationship between the conventional current through the Helmholtz coils and the effects on a compass needle. Suggest that we could use the current readings as a proxy for the magnitude of the force and therefore the external torque. Again, students should be reminded about getting a good spread in data and discuss methods of doing that (i.e. find the smallest and largest measureable current readings within tolerances).
Explain, Elaborate & Closure: Whiteboard NMR Lab results	
Time	Description
30 min	Each lab group will prepare a whiteboard showing their graphical and mathematical models for part (a). The anticipated consensus relationship between the precession frequency, ω_p, and the magnitude of the angular momentum is an inverse relationship where the slope of the linearized graph is the external torque. If there is not consensus use the units of the slope, the y-intercept as well as the correlation for each proposed model to drive the students toward the anticipated consensus. If not possible might have to back up and use the bike wheel demo to help. Each lab group will prepare a whiteboard showing their graphical and mathematical models for part (b). The anticipated consensus relationship between the precession frequency, ω_p, and the proxy the magnitude of the external torque is linear. Since we are using a proxy for the torque there is no reason to believe that the slope of the linearized graph should be the angular momentum. If there is not consensus might have to back up and use the bike wheel demo to help. Have students form a combined consensus model relating the precession frequency, ω_p, to the external torque and the angular momentum assuming the coefficient of the relationship to be one since we were using a proxy for the torque. The anticipated

	combined consensus model is $\omega_p = \frac{\lvert\vec{\tau}_{ext}\rvert}{\lvert\vec{L}\rvert}$. Suggest students plug in the relationships between the angular frequency and period and between angular momentum and rotational inertia, I, to develop a relationship for the period of precession as a function of the torque, rotational inertia and period of rotation. The anticipated relationship is $T_p = 4\pi^2 \frac{I}{\tau T_r}$. Have students compare this model for other SHM phenomena such as a spring-mass system, simple pendulum (less than 15^o displacement), physical pendulum (small displacement), and torsion pendulum and ask them what do all of these phenomena have in common. Anticipated answer: a restorative force that can be modeled as F = -kx which results in SHM. Students will now practice using the consensus models on a few problems which they will whiteboard.
Assessments	
Formative	Formative assessment will happen throughout the experience but especially during the whiteboarding phase when student are forming their conceptions of the relationships. Students will be asked what they think and why. They will be asked to justify their model based on their data. Students might have to be led a bit by pointing out the logical consequences of their model (i.e. the y-intercept indicates that when there is no torque there is still a precession, the units of the slope are not consistent with constants in the lab, your data has a tight grouping what is your certainty that your model would hold up if we were to test in this range, tell us how you got your data, etc.). During the practice whiteboarding, students will engage with one another and myself. This will help students to self-assess their comprehension as I am assessing their comprehension.
Ideas for Differentiation	
Academic	A calibration curve will be provided to the students that relates the current through the Helmholtz coils and the net torque on the magnet in the acrylic ball for students who are hung up on using the current readings as a proxy for the torque. During the experiment, the Helmholtz coils will be constantly powered; however, as an enrichment students could use the relay to set up resonance. Additionally students could then use the computer to adjust the relays to find the resonance frequency.
Physical	Written instructions for the **hearing impaired** students and a video with closed captioning will be provided before class. For the **visually impaired**, perhaps a small gyroscope could help them feel what will be happening. If they are willing, they could be the volunteer, with help, for the second part of the bike tire demo. They will also be provided with the video assuming that a larger view would help. Students with physical limitations will be grouped with students to maximize their contributions.