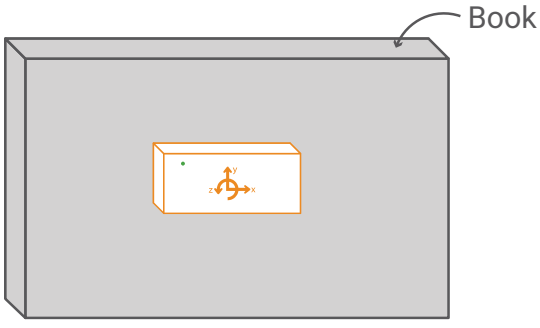
Rotating Book

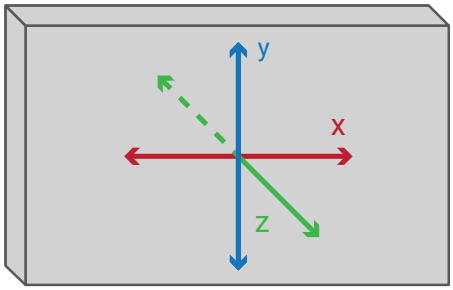
Exploration

The moment of inertia (MOI) is the rotational inertia of an object as it rotates about a specific axis. Moment of inertia determines the torque required for a specific angular rotation about an axis. The moment of inertia depends upon the distribution of mass of the rotating object in relation to the axis the object is rotating about. Explore whether the stability of a book's rotation is dependent upon the moment of inertia and therefore whether it changes based on the axis the book is rotating about.

Materials

- Rectangular prism-shaped object (should look like a book) or old book. The object should be able to open so the PocketLab can be attached on the inside. A plastic VHS or DVD case or cardboard box works well.
- Tape
- PocketLab





I_{yy} = Intermediate moment of Inertia

I_{xx} = Smallest moment of Inertia

I_{zz} = Largest moment of Inertia

Objective

In this experiment, students will:

1. Explore whether the stability of a book's rotation is dependent upon its moment of inertia
2. Determine whether the stability changes based on the axis the book is rotating about.

Method

1. Study the diagram showing the greatest, least, and intermediate moments of inertia along different axes of a rotating book.
2. Tape the PocketLab inside the book/object so it can close. This can be difficult, so perhaps use an old book and cut out a slot for the PocketLab in the pages (an object that resembles a book, but is empty on the inside, like an old, plastic VHS case, will also work).
3. Orient PocketLab to reflect the diagram shown.
4. Rotate the book about each axis by throwing it straight up into the air. Try to keep the force you put into the rotation as equal as possible.
5. For each rotation, record the angular velocity along all three axes.
6. Determine what it means for a rotation to be "stable." Analyze the data to determine the axes with the most stable rotations and the least stable rotations.

Predictions

- Which axes do you think will have a stable rotation? Which axes do you think will not have a stable rotation? Explain your prediction, thinking about the moment of inertia for the different axes.

Data Analysis and Observations

- Describe your own qualitative observations of the book as it rotated about the three axes. Which ones seemed to have a stable rotation, which ones seemed to not have a stable rotation? What did that look like?
- Examine the data more carefully. What was similar and what was different about the graphs of the rotations about the different axes? Use data from the graphs to support your answer.

Conclusions

- Which axis/axes is/are the least stable for the book to rotate about? Why? Use your knowledge of moment of inertia to explain your answer.
- Which axis/axes is/are the most stable for the book to rotate about? Why? Use your knowledge of moment of inertia to explain your answer.

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TEACHER GUIDE

Try to find something that is a rectangular prism, but may be easier than an actual book to use for this experiment. An old cassette case works best as it can open like a book, but a PocketLab can be taped to the inside much easier. To use a real book, a slot in the pages may need to be cut out before the PocketLab is taped down.

The math behind this experiment can get very complicated. An AP Physics classroom may be able to tackle some of it. For more info on the math behind the principles of this experiment, Google “Principles of rotating book about three axes” and you can find a number of sources.

However the basic relationship between moment of inertia and the stability of the object as it spins can be observed through this experiment. This will help in students’ overall understanding of moment of inertia as they will observe how the same object with the same mass can have different moments of inertia depending on the distribution of the object’s mass, relative to the rotating axis. Highlight how this is different from inertia, which is solely dependent on the object’s mass.

If the book is oriented as the diagram shows, the book will show a more stable rotation about its longest axis (y-axis) and its shortest axis (z-axis). The stability of the rotation can be seen qualitatively through visual observation and also quantitatively through the PocketLab’s angular velocity graph. When the book rotates about the longest or shortest axis, the x- or z-axis will display a high rotation relative to the other two axes. The other two axes may display some rotation, but it should be minimal, especially when compared to the axis the book is rotating about. The intermediate axis (y-axis) will not be very stable however. An intermediate moment of inertia in this case, causes less stability. This can be observed visually as the book doesn’t rotate as smoothly about one single axis

and it can be observed in the graph. When the book rotates about the intermediate axis, the graph will still show greater rotation in the y-axis compared to the other two, but there will be a significant amount of rotation in the other axes. Push students to think about how the mass is distributed differently relative to each axis and how that relates to their observations.

Note: A variable that is difficult to control is how precisely the book is thrown about the intended axis and how much force is put into each toss. Remind the students to try to keep the throw as controlled as possible.