multiplied these by the cross-sectional area of the beaker, A, to get the forces on the beaker's bottom, F_1 and F_2. We then subtracted these forces to find the increase in the force, $\Delta F = F_2 - F_1$, which of course yielded $\Delta F = \rho g A \Delta h$. The students were quick to note that $A\Delta h$ was the volume of displaced fluid, which has mass m_{df}. Thus, we had shown that

$$\Delta F = m_{df}\, g \quad (3)$$

We then noted that invoking Newton's third law (Response 2) implies that Eq. (3) is really the buoyant force, B. This was exciting—we had derived Archimedes' Principle without assuming any particular shape for our object.

Once again, experience confirmed that the best lab exercises are those that generate dialog, and also that the teacher can still learn a lot when interacting with students. My task now is to come up with more lab exercises like this *so that I can learn more physics* (and maybe teach a little more effectively too)!

Acknowledgment

I would like to thank the PHY 231 class of Fall 1992 at Union University for their excellent participation in class, particularly that which led to teaching their professor a little more about Archimedes' Principle.

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APPARATUS for Teaching Physics

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Moment of Inertia with PVC Pipe and Iron Rebar

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A nice introduction to the topic of rotational motion can be made with the moment-of-inertia batons that are available commercially for a little over $100.[1] Students will notice that they appear to be identical (unless, of course, they are painted differently). They have the same length, diameter, center of mass, and total weight (which can be verified with a scale). However, when a student attempts to rotate the batons, one of the batons is noticeably more difficult to rotate. The student is unable to observe that the interior of the batons contains a mass of metal. In the one baton the metal is in one piece and centered. In the other baton, the metal is in two equal pieces and located at the ends. The connection between the amount of torque necessary for a given angular acceleration and the distribution of mass can then be discussed as the inner construction of the two batons is revealed. Students will notice that the baton with the mass in the middle rotates more easily.

The batons I've made are inexpensive (less than $10) and easy to construct. All materials are available at local building-supply stores. Each consists of approximately one-meter sections of 1-in PVC pipe. In the middle of one is a 20-cm piece of 1-in diameter rebar (the kind of iron bar used to reinforce concrete). The other pipe has a 10-cm section of rebar located at each end. I found that the rebar did not quite fit into the PVC pipe. The metal has a ribbed outside that needs to be ground

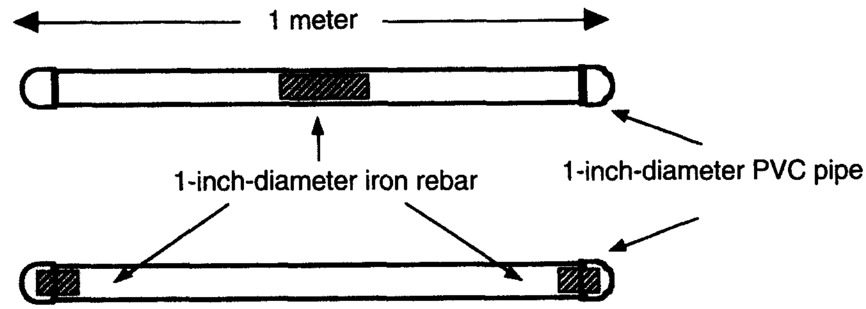

Fig. 1. Moment-of-inertia batons.

down a bit. Using coarse emery paper is possible but slow; a power grinder is definitely the way to go if one is available. I ground mine down just enough to make a snug fit that actually required hammering into position. This eliminated the necessity of gluing the metal into place. Both pipes have 1-in PVC end caps so that initially students are not able to see the inner construction (see Fig. 1). I painted my batons different colors so I could distinguish one from the other without handling them, but this isn't essential.

The difference in moments of inertia is not difficult to determine since the geometry of both batons is rather uncomplicated. The baton with the centered metal piece can be thought of as being two centered slender rods with their axes through the center and, as a first approximation, the other baton can be thought of as one slender rod with its axis at the center together with two point masses rotating at a specific radius (0.45 m) from the axis. The calculations for the moments of inertia for my batons follow.

For the baton with the iron centered:

$$I = I_{PVC} + I_{IRON} = \tag{1}$$

$$\frac{1}{12} M_{PVC} {L_{PVC}}^2 + \frac{1}{12} M_{IRON} {L_{IRON}}^2 =$$

$$\frac{1}{12} (0.478 \text{ kg}) (1.0 \text{ m})^2 +$$

$$\frac{1}{12} (0.798 \text{ kg}) (0.20 \text{ m})^2 = 0.042 \text{ kg} \cdot \text{m}^2$$

For the baton with the iron at the ends:

$$I = I_{PVC} + I_{IRON} = \tag{2}$$

$$\frac{1}{12} M_{PVC} {L_{PVC}}^2 + 2 (M_{IRON} {R_{IRON}}^2) =$$

$$\frac{1}{12} (0.478 \text{ kg}) (1.0 \text{ m})^2 +$$

$$2 \left(\frac{0.798 \text{ kg}}{2}\right) (0.45 \text{ m})^2 = 0.20 \text{ kg} \cdot \text{m}^2$$

The second calculation shows a moment of inertia almost five times greater than the first, and the subjective test of trying to rotate these at the same time with the same angular acceleration (which is the natural way to rotate these if one is in each hand) bears this out.

This demonstration intrigues and fascinates students. I like it especially because after students understand the geometry of the batons, it is natural for them to predict that distribution of mass is an essential aspect of rotational motion. This early understanding often gives the confidence that so many students seem to need in order to grasp the subtleties of rotational dynamics.

Reference

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An Instrument to Show Relative Motion

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One of the basic features of the description of motion is the interdependence of a trajectory and its reference system. The shape of the trajectory in one reference system may be absolutely different in a second reference system. To demonstrate this basic and interesting feature of motion, we have developed a simple instrument that can easily be used during a lecture, with the results immediately visible on the blackboard.

Construction

The basis of the instrument is a rotating wheel (refer to Fig. 1). Make a square hole in the center of a wheel (1), attach a square pivot to the axle (2), and push axle and wheel together with a tight fit to eliminate backlash. Near the edge of the wheel make a round hole into which will go a short pipe (3). Make several such holes along the wheel's radius so that the pipe can be placed at different distances from the axis of rotation. (By this means students can investigate the point trajectories that are not located on the wheel's edge.) Place a weak spring (4) inside the pipe. This spring holds two sharpened pieces of chalk (5) that protrude from either end of the pipe. One piece of chalk will face the blackboard (10), the other faces a transparent (Plexiglas) plate (6) also placed on the axle. Slide a rotating sleeve (8) around the axle, securing it with a nut (7).