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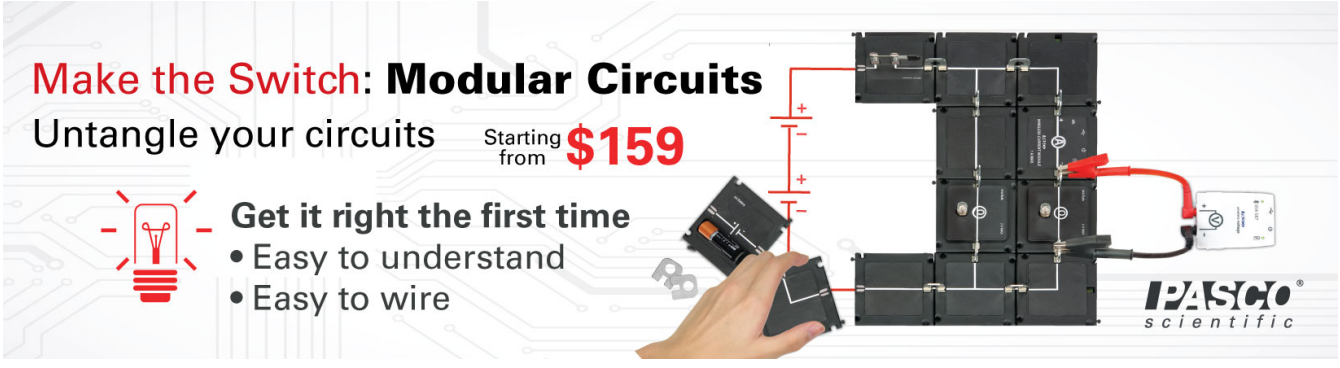

The Breaking Broomstick Demonstration

By Karl C. Mamola and Joseph T. Pollock

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The remarkable demonstration illustrated in Fig. 1 has been known for several centuries. It was described in a classic literary work[1] as early as the year 1532. The figure shown here, along with an accompanying discussion, was first published[2] in 1881 as an "Experiment to Demonstrate Inertia." It has since been reprinted in a number of places.[3,4] The description and instructions given in Ref. 2 are as follows:

Fig. 1. The Breaking Broomstick Demonstration as illustrated in Refs. 2–4.

> ***"A needle is fixed at each end of the broomstick, and these needles are made to rest on two glasses, placed on chairs; the needles alone must be in contact with the glasses. If the broomstick is then struck violently with another stout stick, the former will be broken, but the glasses will remain intact. The experiment answers all the better the more energetic the action."***

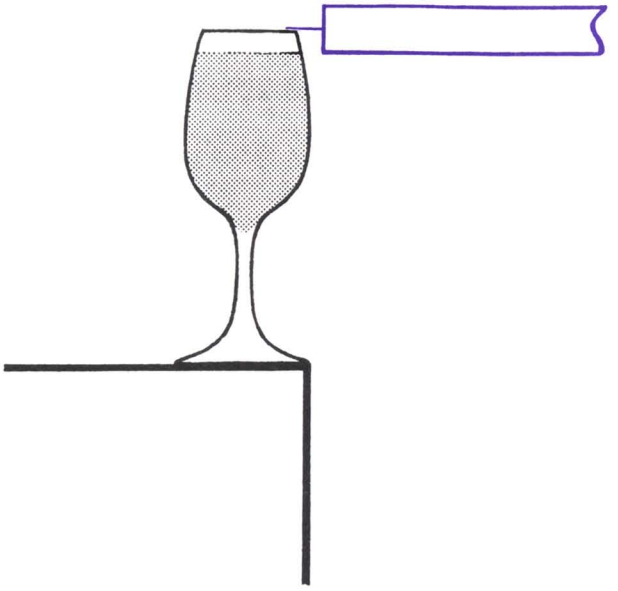


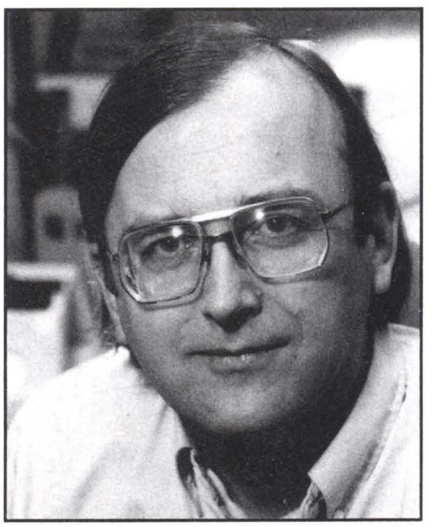
Fig. 2. "Fail-safe" method of supporting the stick. Note the clearance between the end of the stick and the widest part of the glass (and also the edge of the table).

Some Experimental Details

We have performed this demonstration using a number of different kinds of "broomsticks" sold in grocery and hardware stores. Most of these are about 1.2 m long and around 2 cm in diameter. There is a great deal of variability in the behavior of such sticks, depending primarily on the species of wood. Some, especially those made of certain hardwoods, split unpredictably when struck or are very difficult to break, and therefore don't work well for this demonstration. Others, made of a wood such as white pine, break quite consistently and reliably. It's not always easy to determine beforehand whether a particular kind of stick will be suitable or not, so it's best to buy several that are nominally the same to practice with before demonstration time. Our preference is for homemade sticks fashioned from eastern red cedar with a router. These sticks are 1.5 to 1.8 m long and have a diameter of 2.5 cm.

Instead of needles at the ends, we use straight pins (the kind used in sewing) with the heads removed. For dramatic effect, we use filled wine glasses that are as fragile looking as we can find. The demonstration is easier for a large class to see if the glasses are placed on tables rather than on chairs. As for the "stout stick" for striking the broomstick, we usually use a steel table-clamp rod that is 1.0 m long and 1.3 cm in diameter.

Figure 2 shows a "fail-safe" way of setting up the demonstration that virtually insures that no harm comes to the glasses. With the ends of the stick supported as shown, the glasses should survive intact even if the demonstration fails otherwise. There is clearance between the end of the stick and the widest part of the glass (and also the table) so that even if the stick should happen not to break, the rim of the glass will have to endure only the minute force required to bend the pin. Moreover, if the glass is shaped as shown (with the rim having a smaller radius than the base), the torque due to this small force cannot tip the glass over. Even if this fail-safe setup is used, it is prudent to first practice one's technique a few times using, as recommended by Resnick et al.,[4] unbreakable supports such as plastic cups or soft-drink cans rather than glasses.



Joe Pollock *received his B.S. (1972) and M.S. (1975) in astronomy from Penn State University and Ph.D. in astronomy from the University of Florida (1982). Having arrived at Appalachian State in 1981, he is an associate professor in the department of physics and astronomy. Although an astronomer by profession, he also teaches the junior-level laboratory-techniques course for physics majors and has in the process developed an interest in new, novel, and dramatic physics demonstrations.*

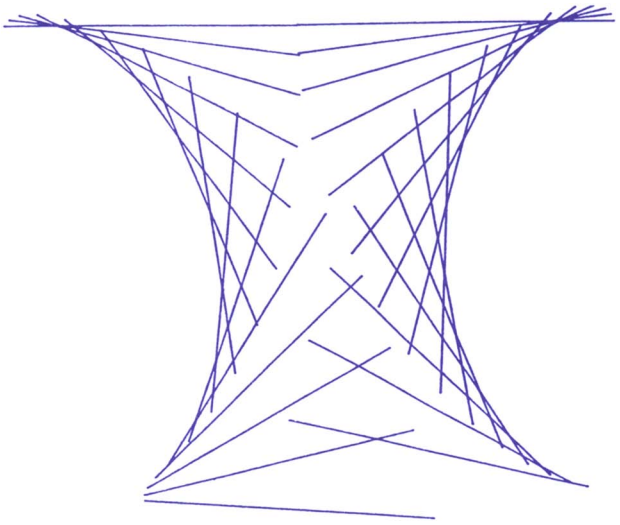


Fig. 3. Detailed motion of breaking stick. The action was recorded using a video camera operated at 60 Hz with a 1/1000-s exposure time. The images were captured with a frame grabber. The output appears as a computer-generated stick figure representation of the digitized frames.

Theory

Evidently the only published explanation of this demonstration is that found in Refs. 2 and 3:

> It is explained by the resistance of inertia in the broomstick. The shock suddenly given, the impulse has not time to pass on from the particles directly affected to the adjacent particles; the former separate before the movement can be transmitted to the glasses serving as supports.

This discussion does not account for the actual motion of the breaking stick. We have made high-speed video recordings that show that the initial motion of the ends is almost always *upward*; they rise up off the glasses when the blow is struck (see Fig. 3). Moreover, this motion of the ends is seen to be simultaneous with the deformation of the center; there is no noticeable time lag.

A simple model for the breaking stick, which does account for the important details of its motion, is illustrated in Fig. 4. Two half-sticks, each of mass M and length L, are connected by a stiff massless hinge. An average force $2F$ is applied to the hinge for a brief time Δt, after which the hinge separates and the two stick halves fall only under the influence of gravity. The impulse $F\Delta t$ imparted to each half of the stick results in a center-of-mass velocity given by

$$v_{CM} = F\Delta t/M \qquad (1)$$

At the same time, there is an associated impulsive torque $F\Delta tL/2$ about the center of mass of each half. This is accompanied by a resisting torque τ due to the stiffness of the hinge. The stiffness depends, until the elastic limit is exceeded, on Young's modulus of the wood. The resulting angular velocity imparted to each of the stick halves about its center of mass is

$$\omega = FL\Delta t/2I - \tau\Delta t/I \qquad (2)$$

where $I = ML^2/12$. The resultant velocity of the end of the stick is therefore given by

$$v_e = (-2v_{CM} + 6\tau\Delta t/ML) + v_{CM} \qquad (3)$$

This velocity will be negative (i.e., directed upward) if τ is sufficiently small. In the case of a "completely free" hinge that offers no resisting torque, Eq. (3) implies that the applied impulse will result in an upward speed of the ends that has half the magnitude of the downward speed of the hinge. For an actual stick, (see Fig. 3) the speed of the ends is somewhat lower. It follows from Eqs. (2) and (3) that in the case of a free hinge, the points on the stick halves that are initially at rest (the instantaneous axes of rotation) are located two-thirds of the distance from the center. The measured positions of these points for an actual stick (see Figs. 3 and 4) are always somewhat closer to the ends. If the stiffness is sufficiently great, it is possible that the instantaneous rotation axes will lie beyond the ends of the stick (so that the initial velocity of the ends is downward) or that the stick will not break at all.

An Interesting Variation

The fact that the ends usually rise when the stick is struck suggests that the demonstration can be done a bit more simply by resting the stick ends directly on the rims of the glasses. Indeed, there is no mention of the use of needles or pins in the description given by Rabelais.[1] We have attempted the demonstration this way and found that it does work—sometimes. There are a couple of problems. For example, if the applied impulse is not almost exactly vertical, the stick will exert horizontal forces on the glasses and one or both may tip over. The pins, on the other hand, are relatively free to flex and slide over the rims and so exert much smaller forces. Also, if the blow is struck off-center, the geometry is no longer symmetric and, without the use of pins, one glass may experience a force sufficient to fracture it. An additional concern is that low amplitude shear waves may be excited by the applied impulse and superimposed on the motion described above. These waves propagate down the stick and may deliver a substantial impulse to the rims of the glasses. Small indentations in the wood may in fact be seen at the points of contact. The pins serve to reduce the magnitude of these impulses. We have found that while it is possible to perform the demonstration in this simpler way, the risk of

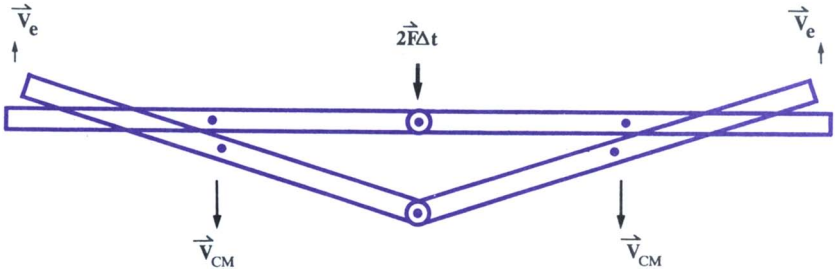


Fig. 4. Stiff-hinge model of the breaking stick.

failure is substantially greater and a much more precise striking technique is required.

Conclusion

We have found the breaking broomstick demonstration to be a very interesting and instructive one that is suitable for presentation at a variety of levels. At the most elementary level it can be shown as simply a dramatic "inertia" demonstration, neglecting the details of the motion. It may also be presented at a somewhat higher level and accompanied by an analysis of the dynamics of the motion. This might also include measurements of the linear and angular velocities of the stick halves after impact. These values, obtained from a strobe photograph or from transcribed images such as those in Fig. 3, may be used to estimate the magnitudes of both the applied impulse and the resisting torque. It is also instructive to examine the horizontal motion of the centers of mass of the halves as they fall. They approach each other with a constant horizontal velocity that is imparted as the "hinge" closes slightly during the impact.

Acknowledgments

The authors wish to thank David Randell who made a large supply of cedar "broomsticks" for us and Harold O'Bryant who spent hours producing high-speed video recordings of our breaking them.

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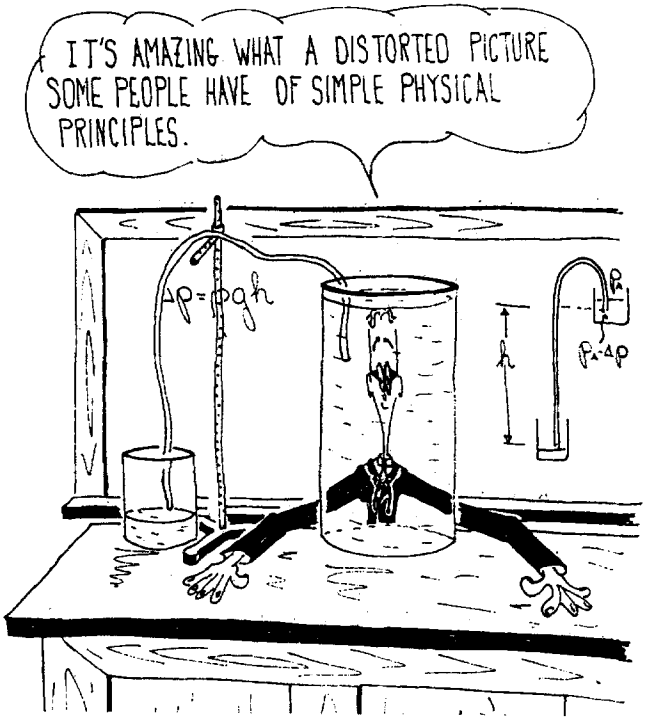

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