an effect which changes T by 0.1% should not be included if T itself can only be measured to an accuracy of 1.0%. The important thing about the pendulum is that it is possible to detect deviations from the simple $2\pi\surd(l/g)$ expression even with the usual apparatus available. Thus, for $\theta=60°$, the series in Eq. (1) has the value 1.07, well within experimental verification. On the other hand, the corrections arising from treating the simple pendulum as a compound pendulum will in general not be observable.

An additional virtue of the simple pendulum experiment is that it is an open experiment. The good student can always find additional things to do. With very little additional effort it is possible, by electrical means, to improve the accuracy in the measurement of the period by a factor of 10. The student can then observe how more of the exact expressions must be retained in order to agree with experiment. In fact, with increased accuracy in the measurement of T, the student might find that he is unable to get agreement with Eq. (1). In arriving at the expression we have neglected altogether any frictional effects. In actuality the pendulum is a damped system and hence, will have its frequency altered, in the well-known way. By measuring the decay time, the student can determine the damping constant and hence, recalculate the period with damping effects included.[1]

Although we have used the simple pendulum to illustrate the relation between approximation and accuracy of measurement, almost any physical system can be used. The essential feature is that there must be associated with it a derived quantity which is expressible in terms of an "exact" expression which is amenable to approximation. In this way the student can begin to get a feeling for what goes into a physical experiment and at the same time, realize that physics is not "simple."

[1] See, for example, F. C. Champion and N. Davy, *Properties of Matter* (Prentice-Hall, Inc., Englewood Cliffs, New Jersey, 1937), Chap. 2.

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LETTERS TO THE EDITOR

Angular Momentum and Tippe Top

ALTHOUGH the fact that the tippe top[1] turns itself over is amazing enough—and by now well known—the fact that it rotates opposite to what most students think the direction of rotation should be is not well known. This unexpected twist to the student's line of reasoning makes the top an excellent illustration of the conservation of angular momentum. It has never failed to excite the student's imagination.

The demonstration can be effected in three parts, namely: (1) Spin the top on a flat surface as shown in Fig. 1(a). The top will quickly turn itself upside down and continue to rotate on its stem until its energy is dissipated, whereupon it falls on the table and resumes its normal equilibrium position of stem up. (2) Repeat what seems to be the motion of the top without actually releasing it. That is, hold the stem of the top in a normal starting position [Fig. 1(a)] and twist the stem between the thumb and forefinger. At the same time rotate the hand slowly to invert the top. If the top is initially twisted in the direction of an arrow painted on it, then the audience can clearly see that the inverted top continues to rotate in the direction of the arrow. Hence they come to the conclusion that once the top is started in the direction of the arrow, it will continue to rotate with the painted arrow even when inverted. (3) Now spin the top as in part (1) and when it inverts itself ask the audience to determine the actual direction of spin by close observation.

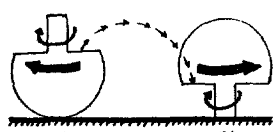

FIG. 1. Tippe top. (a) Position at start of rotation. (b) Inverted position.

Everyone is genuinely surprised to find that the inverted top is not spinning in the direction of the arrow painted on it but opposite to this direction as shown in Fig. 1(b).

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[1] C. M. Braams, Am. J. Phys. 22, 568 (1954).

Dunking Duck

IN a previous article[1] Julius Sumner Miller proposed an explanation of the physics involved in the Dunking Duck, a toy often observed in shop windows. His explanation involves direct condensation of a vapor within the duck's head, a process that might be expected to proceed rather slowly. In any event, a model of this toy in my possession operates by a different mechanism. According to Mr. Miller, the essential construction of the toy is a glass tube with a glass bulb blown on each end. From the external appearance this would seem to be correct, but at least in my model the glass tube extends down into the lower bulb which serves as the duck's posterior (Fig. 1). The "body" and posterior of the duck are painted yellow (this hides the interior), and a red feather and hinged plastic wings are added, chiefly for adornment. A solid beak is glued to the head, and the head and beak are covered with a red absorbent material; hence the entire head becomes damp when the beak is wetted. Mr. Miller's

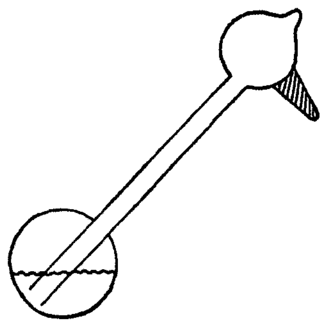

FIG. 1. Essential construction of duck's body.

description of how the duck's body is mounted so as to be able to place its thirsty beak in a glass of water is quite correct, as well as his instructions for starting the action. My explanation of the operation is as follows. The lower bulb is filled almost half full with a volatile liquid. When the beak is first wetted, the duck's head becomes cool by evaporation. This cooling of the head rapidly decreases the vapor pressure in the head and the greater pressure in the lower bulb forces the liquid up the tube into the head thus shifting the center of gravity of the duck toward the head. The head now dips down, the wings flop forward, furthering the shift of the center of gravity, and the duck "takes another drink." However, as the head dips down, the lower end of the tube projecting into the posterior bulb rises above the level of the remaining liquid. A series of vapor bubbles then surges up the tube, equalizing the pressures. Since the tube connecting the two bulbs never becomes horizontal, even when the head is lowered, the liquid runs back down the tube into the lower bulb, shifting the center of gravity toward the duck's posterior. Accordingly, the duck raises its head from the water, and the process is then repeated. Speeding up the cycle is accomplished by hastening the evaporation. This may be done by directing a fan on the duck's head as suggested by Mr. Miller.

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[1] Julius Sumner Miller, Am. J. Phys. **26**, 42 (1958).
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Doppler Effect and Time Dilatation

THE recent letter by R. H. Bacon in this Journal[1] suggests a trivially simple derivation of the time relation in the relativistic twin problem. Bacon refers to a straight line journey to Sirius and return by twin B while twin A stays put in accordance with the usual stage directions. Remote periodic variable stars in the plane bisecting the line of travel are used as clocks by both twins. To avoid nonessential complications these stars are taken at rest in the bisecting plane (that means at rest with respect to the stay-at-home twin A). Of course each twin carries with him a good local clock (periodic mechanism, physiological processes, etc.).

Both twins count the same number of periods during the complete round trip. But B observes a shorter period than A because of the transverse Doppler effect. The frequencies are related by

$$\nu_B = \nu_A \frac{1+\beta\cos\theta_A}{(1-\beta^2)^{\frac{1}{2}}}$$

$$= \nu_A \frac{1}{(1-\beta^2)^{\frac{1}{2}}}, \qquad (1)$$

since $\theta_A = \pi/2$ (remote sources at rest in the bisecting plane). These frequencies are inversely proportional to the times (T_A and T_B) recorded by the local clocks for the complete journey. Consequently

$$T_B = T_A(1-\beta^2)^{\frac{1}{2}}. \qquad (2)$$

Since the observers are not equivalent there is no paradox. The same relation can be derived from the formula for the longitudinal Doppler effect.[2]

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[1] R. H. Bacon, Am. J. Phys. **26**, 502 (1958).
[2] Henri Arzeliès, *La Cinématique Relativiste* (Gauthier-Villars, Paris, 1955), p. 145. J. D. Robinson and E. Feenberg, Am. J. Phys. **25**, 490 (1957).

Low Molecular Weight Polyethylene as a Damp-Proof Insulation for Electrostatic Equipment

PHYSICS teachers avoid performing experiments in static electricity fearing that dampness may hinder the desired effect. A recently developed material used in industry for manufacturing hard waxes, called "Low Molecular Weight Polyethylene," shows remarkable electrical properties as far as resistance to moisture is concerned.

The new insulating material allows one to perform successfully experiments during the most humid days, even at 95% humidity. It has been exposed to severe tests without failure.

We placed in a home refrigerator 5 Braun electroscopes with polystyrene insulation and 5 identical electroscopes with LMP insulation. After an hour's time, the electroscopes were exposed to room conditions. The moisture condensed on the polystyrene insulation caused discharging of electroscopes in a few seconds. No visible change in deflection on the LMP-insulated electroscopes was noticed.

Blowing breath on the conventional insulation of a charged Braun's electroscope causes immediate discharge. No loss of charge was noticed in the electroscope with the new insulation. A drizzle of rain to which these electroscopes were exposed scarcely affected the deflection.

Low-molecular weight polyethylene is similar to paraffin, but much harder. (Paraffin, average molecular weight 600; LMP, 2000). This material can be easily cast to any desired form, such as rods, bushings, and plates, and can be easily machined.