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Use of Motion Pictures in Laboratory Dynamical Studies

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IN student laboratory experiments in dynamics, as, for example, Newton's second law of motion or the conservation of momentum, it is, of course, highly desirable to allow motion with the least possible constraint and to observe the displacements of moving parts without using perturbing markers. This circumstance has led us to use motion pictures in the student laboratory for quantitative observation of rapid dynamic processes, a technique which is used in a well-known textbook.[1] The photographic method combines maximum freedom of movement with accurate observation of position as a function of time, if the camera frame speed is sufficiently high.

A double pendulum apparatus, with which we have studied the conservation of momentum in the student laboratory, is shown in Fig. 1. It consists of two wooden blocks, each suspended by a steel rod from a common free-swing pivot and counterweighted in such a way that the center of mass of each pendulum is at the center of its wooden block. A spring is compressed between the two blocks, and they are tied together with a thread. When this thread is burned, the pendulums recoil. The mass of each block can be varied at will.

The motion is photographed with a motion picture camera at 64 frames per second. The camera used in this work was a war-surplus gun-point aiming camera, adapted only to the extent of adding a viewfinder. Since there is a coordinate screen behind the pendulums, the student can determine the heights to which the blocks rise by examining the film with a magnifying viewer.

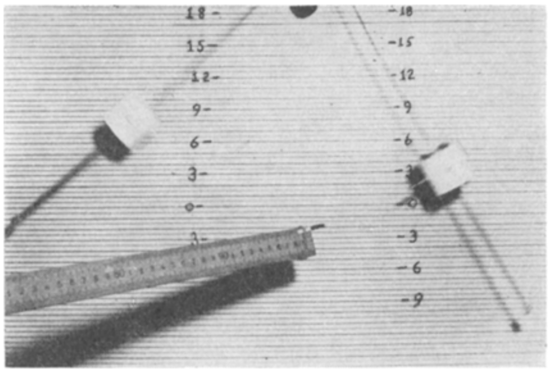

FIG. 1. A frame from movie film of the recoil pendulums flying apart after the burning of the binding thread. In this frame the pendulums are not near the end of their swing and are not completely stopped by the camera. The numbers are retouched for clarity in reproduction; they show clearly in the original.

Since each pendulum receives the same impulse, the initial angular momenta are equal, giving

$$(I_1+M_1r^2)\omega_1=(I_2+M_2r^2)\omega_2. \qquad (1)$$

Here ω_1 and ω_2 are the initial angular velocities of the two pendulums, I_1 and I_2 are the respective moments of inertia about axes through the centers of mass parallel to the actual axis of rotation, M_1 and M_2 are the respective total masses, and r is the common distance from each center of mass to the axis of rotation. By the conservation of energy we have

$$\tfrac{1}{2}(I_1+M_1r^2)\omega_1^2=M_1gh_1,$$
$$\tfrac{1}{2}(I_2+M_2r^2)\omega_2^2=M_2gh_2, \qquad (2)$$

where h_1 and h_2 are the respective heights to which the centers of mass rise. Combining Eqs. (1) and (2), we find

$$\frac{h_1}{h_2}=\frac{M_2(I_2+M_2r^2)}{M_1(I_1+M_1r^2)}. \qquad (3)$$

The moments of inertia I_1 and I_2 can be calculated from the geometry of the pendulums; or if they are constructed such that $I_1 \ll M_1r^2$ and $I_2 \ll M_2r^2$, then Eq. (3) reduces

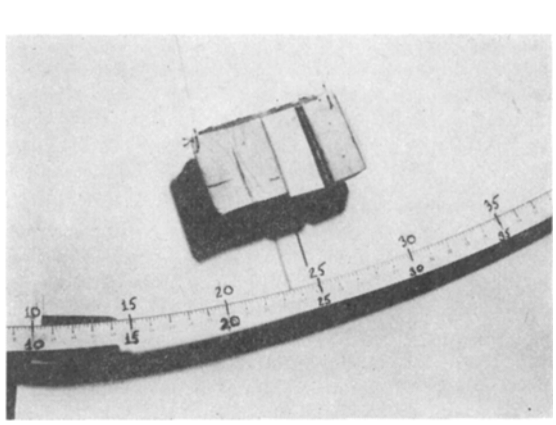

FIG. 2. A frame from movie film of a ballistic pendulum recoiling after being struck by a bullet. The numbers are retouched for clarity in reproduction; they show clearly in the original.

to

$$h_1/h_2 = M_2^2/M_1^2. \tag{4}$$

The student may use his data to verify this prediction.

One may also obtain the initial kinetic energies from Eq. (2), and thus study the sharing of energy in recoil. Agreement with expected results, to within about one percent, is obtained.

Another laboratory study to which motion picture photography lends itself is the measurement of rifle muzzle velocities with the ballistic pendulum. Although keenly interesting to most students, this experiment is often considered too dangerous for class work; the probability of a serious accident is never negligible. However, if the experiment is photographed beforehand by the instructor, the student may study the film in safety. Figure 2 is a sample frame taken from a 64-frame-per-second photograph of a ballistic pendulum. The deflection of the block is measured in degrees, the numbers being read from the pictures, and the height of rise calculated from the deflection and the length of the pendulum.

Other possibilities in dynamics suited to photography suggest themselves, such as falling bodies and billiard-ball collisions.

Some readers may believe that this method of laboratory study denies to the student the freedom of manipulating the apparatus. However, this disadvantage is minimized by having the student perform all operations except the actual photography (and, in the case of the ballistic pendulum, the actual firing). The disadvantage is further balanced by the improvement in accuracy which is gained when mechanical restrictions on the movement of the apparatus are removed.

[1] Lemon and Ference, *Analytical experimental physics* (University of Chicago Press, 1946).