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# Stroboscopic Study of Motion

JOSEPH BALL[1]

*Abstract.* A stroboscopic method for demonstrating Newton's three laws of motion is described. By means of a camera and mechanical stroboscope, photographs are made from which measurements are taken to justify these laws.

## EQUIPMENT AND LIGHTING TECHNIQUE

The camera used was an f:3.5 Minolta Autocord, a twin-lens reflex camera. In all my work I used Kodak Verichrome Pan film and rated it at ASA 200. The film was force-developed in a fine-grain developer and printed on very high contrast paper. To obtain my results I mounted the camera behind a mechanical stroboscope. The stroboscope was a metal disc attached to a two pole phonograph motor; there were two slits in the disc's edge, and it rotated at six revolutions per second, hence the frequency of openings was twelve per second.

The problem of obtaining good lighting was solved by the method shown in Figure 1. Two photoflood bars were placed on either side of the subject area. These were masked so that no light fell on the black cardboard background placed about six feet behind the subject. Since the background would receive twenty or thirty times as much exposure as the subject, it was essential that it be kept absolutely dark.

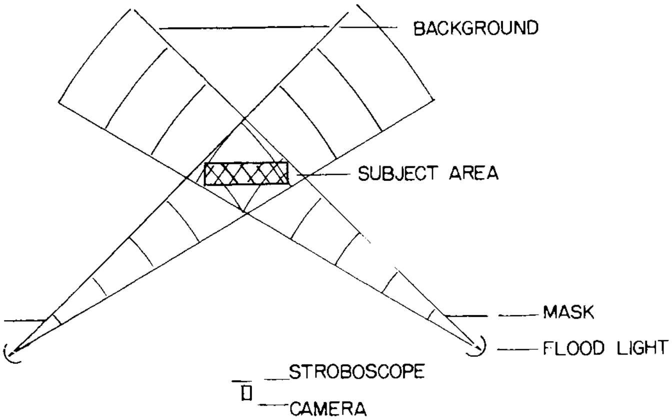

Figure 1. Diagram of lighting set-up used.

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## NEWTON'S FIRST LAW

Newton's first law is the law of inertia that states that if a body is set in motion, it will continue in motion along a straight line if acted upon by no external force. To demonstrate this concept, I used a device called an air puck. This is a smooth disc with a hole in the center through which air is forced. When the puck is placed on a flat surface, the air from a balloon mounted on top of it is forced out the hole and along the edges of the disc. This creates a near-frictionless surface of air for the disc to float upon. To obtain photographs, I first set the stroboscope in motion; an assistant gave the puck a gentle push, and as it glided across the field of view, I opened the camera shutter. The result upon development of the film was a series of twelve exposures per second superimposed on the negative, as in Figure 2.

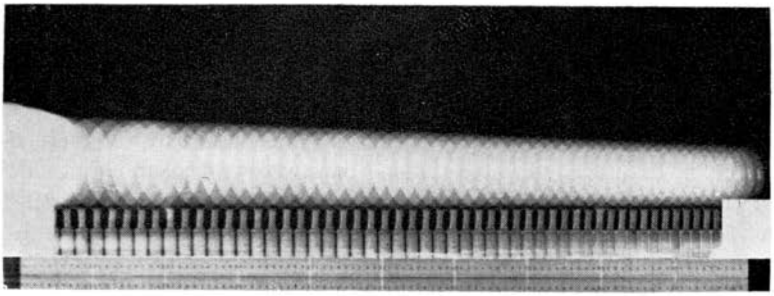

Figure 2. Photograph illustrating Newton's first law of motion. Note that distance between air puck during each interval is nearly constant.

It can be seen that the puck seemed to have a constant velocity, as the distance traveled in each interval was nearly the same. There was, however, a deceleration of 1.76 cm/sec$^2$ due to friction. This calculation was obtained by direct measurement of the photograph. A meter stick was placed behind the disc when it was photographed, and measurements were read from this. In this way Newton's first law was qualitatively demonstrated.

## NEWTON'S SECOND LAW

To demonstrate Newton's second law, I used a device called an Atwood Machine. This is a thread looped over a pulley with a weight attached at each end. Newton's second law states that force on a body is proportional to the rate of change of momentum of the body. In Figure 3, which is a composite of four photographs, I kept the total mass constant and varied the force to see how force and acceleration were related. In every case, $m_1 + m_2 = 200g$. The force available for acceleration in each case was the vector difference of the force on each mass, *i.e.*, $f = (m_2 - m_1) \cdot g$, g being the constant 980 cm/sec$^2$. Table 1 lists the masses $m_1$ and $m_2$ in each case, the force available for acceleration, and the rates of acceleration as measured from the photographs. Measurement was possible because in the original situation fine wires were strung across behind the Atwood Machine at a distance of 10 cm apart. Figure 3 shows the four cases from which the data were obtained.

It can be seen immediately that as force decreases, acceleration rate also decreases. A graph of force vs. acceleration reveals a straight-line relationship, indicating that $f \propto a$.

In every case in Figure 4 the force for acceleration was kept

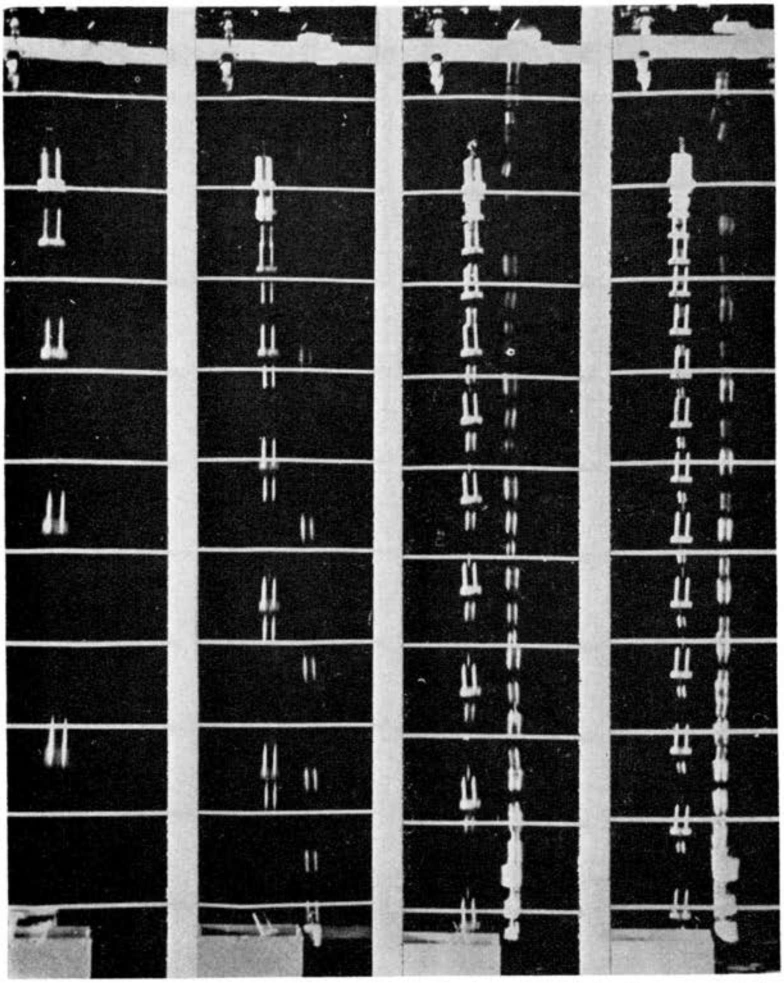

Figure 3. Four photographs of Atwood Machine with total mass being kept constant in each case. Left and right masses are from left to right: 200-0, 150-50, 120-80, 110-90. Note that as force decreases from left to right, acceleration also decreases.

Table 1

Constant Mass

| | Left mass $m_2$ (grams) | Right mass $m_1$ (grams) | Total mass $m_1+m_2$ (grams) | Force $(m_2-m_1)\cdot g$ (dynes) | Measured acceleration (cm/sec/sec) |
|---|---|---|---|---|---|
| Case 1 | 200 | 0 | 200 | 196,000 | 984 |
| Case 2 | 150 | 50 | 200 | 98,000 | 475 |
| Case 3 | 120 | 80 | 200 | 39,200 | 193 |
| Case 4 | 110 | 90 | 200 | 19,600 | 105 |

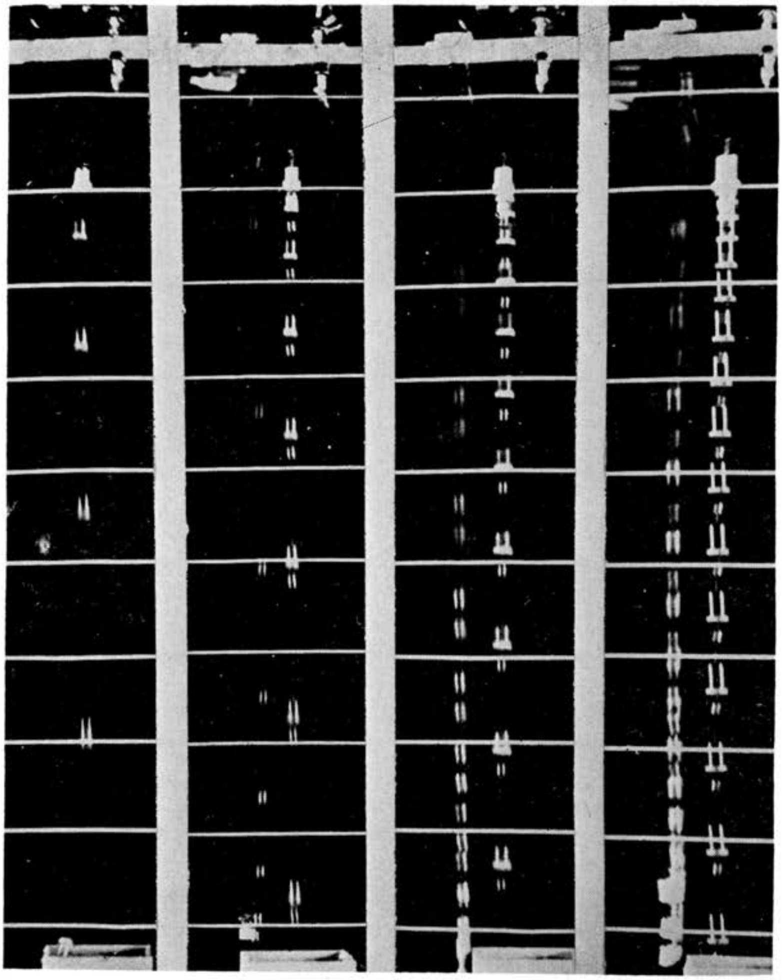

Figure 4. Four photographs of Atwood Machine with force available for acceleration being kept constant in each case. Left and right masses are from left to right: 0-20, 10-30, 40-60, 90-110. Note that as total mass increases from left to right, acceleration decreases.

constant and the total mass to be accelerated was varied; in every case $(m_2 - m_1) \cdot g = 19{,}600$ dynes. The data obtained from Figure 4 are listed in Table 2 below.

**Table 2**

Constant Force

| | Left mass $m_1$ (grams) | Right mass $m_2$ (grams) | Total mass $m_1+m_2$ (grams) | Force $(m_2-m_1) \cdot g$ (dynes) | Measured acceleration (cm/sec/sec) |
|---|---|---|---|---|---|
| Case 1 | 0 | 20 | 20 | 19,600 | 977 |
| Case 2 | 10 | 30 | 40 | 19,600 | 450 |
| Case 3 | 40 | 60 | 100 | 19,600 | 182 |
| Case 4 | 90 | 110 | 200 | 19,600 | 105 |

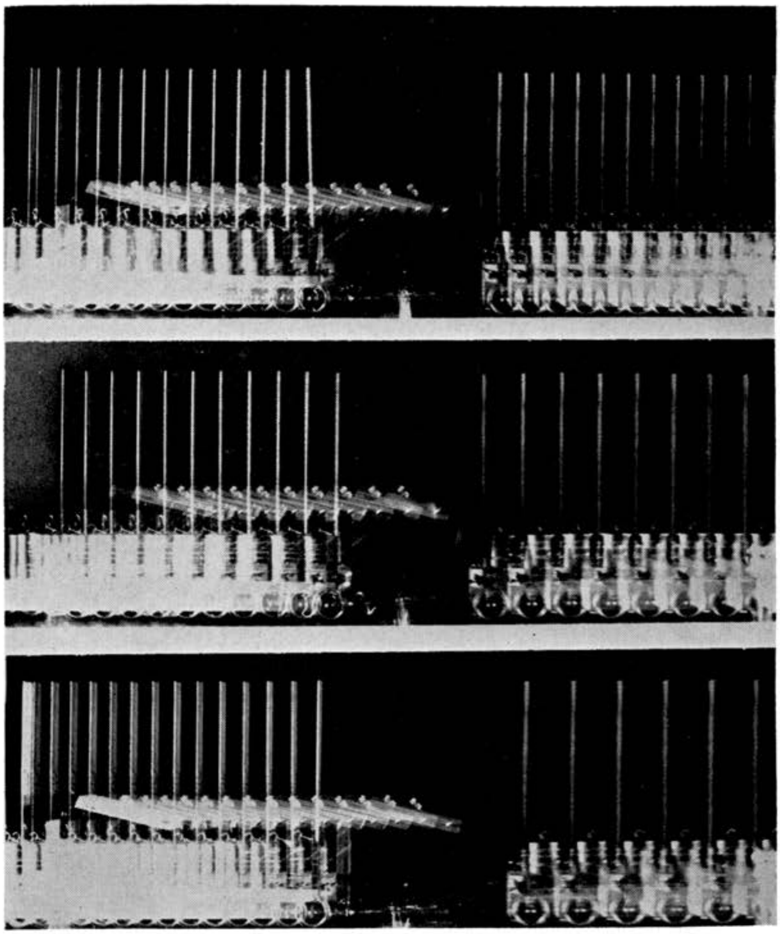

Figure 5. Three photographs of laboratory carts rolling apart after release of spring-loaded hinge on left cart. Note that as the weight of the right cart decreases from top to bottom the velocity of each cart changes, but the total momentum appears to remain constant.

As total mass increased, acceleration decreased. A graph of mass vs. reciprocal of acceleration tends to show a straight-line relationship, hence mass is inversely proportional to acceleration, $m \propto 1/a$. Using these relationships, $f \propto$ and $a \propto 1/m$, I derived that $f \propto ma$. But since acceleration is defined as time rate of change of velocity ($a = \triangle v/t$), the above relationship would read $f \propto m\triangle v/t$ or $f \propto \triangle mv/t$, which is time rate of change of momentum.

## NEWTON'S THIRD LAW

Newton's third law states that for every action force there is an equal and opposite reaction force. I demonstrated this law with wooden laboratory carts. These are wooden blocks with ball-bearing wheels. On the front of one of them were two pieces of wood connected by a spring-loaded hinge. When the hinge was released, the carts went rolling away from each other with equal and opposite momenta. This conservation of momentum concept is shown in Figure 5. In the upper photograph, the weights of the carts were equal; in the middle photograph, the right cart weighed one kilogram less than the left one; and in the lower photograph, the right cart weighed two kilograms less than the left one. These photographs qualitatively demonstrate Newton's third law of motion and the law of conservation of momentum.

This stroboscopic technique could be used to demonstrate the results of particle collision, the laws of angular motion, and the concepts of potential and kinetic energy. This type of work can be a powerful audio-visual aid in the teaching of physics.