LI. POGGENDORF'S FALLMASCHINE.

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Every instructor of elementary mechanics has the problem of teaching the apparent change of weight of a body near the earth, when that body is moving toward or away from the earth with an accelerated motion. An apparatus which will show, both qualitatively and quantitatively, that the force necessary to accelerate a body upwards is greater than the weight of the body, is certain to be of real use to the teacher and a real help to the student.

The Atwood's Machine, though useful, leaves much to be desired. More than two years ago the writer designed an Atwood's machine in which a helical spring supported one of the accelerated masses. When the mass was accelerated upwards the spring stretched more, and when accelerated downward stretched less, than when the mass was at rest. This machine had the good qualities specified in the first paragraph but it had two bad features. First, the scale which was observed by the student, moved with the mass; this was not satisfactory. Secondly, a spring which was sensitive to small changes in stretching force, and at the same time capable of supporting a load large enough to cause these small changes, for conveniently small accelerations, was inconveniently long and its mass was not small compared to that of the attached body.

A few months ago the writer received some advertising material concerning Arnold Berliner's "Lehrbuch der Physik." Among the eight figures of the textbook which were shown, was one entitled "Fallamaschine von Poggendorf". A much improved design of this machine is shown in the accompanying figure. This machine has the good qualities but neither of the bad features mentioned above.

The machine is essentially a modified equal-arm balance. The beam B is built up of two iron bars between which are mounted two pulley wheels *A* and *C*, and one knife-edge *J*. A knife-elge *K* is fastened so as to project out from each side of the double-bar beam. These knife-edges *K* rest in a U-shaped support *S* (only one side shown) which is clamped to a tall rod attached to the lecture desk. The axles of the wheels are made as small as possible so that the friction causes only a small torque about the axis of rotation *K*. The slider *R* serves to balance the beam accurately. The sensitivity of the balance is adjusted by changing the position of the mass L on the pointer P which is attached to the beam B.

The operation of the apparatus is very simple. After the beam has been balanced by using the slider R, a mass M is attached to each end of the long fine linen cord. The downward force of the beam due to the weight of M-below-A, is balanced by placing a mass M in the scale pan supported by the knife-edge J. If now a small mass m is added as shown in the figure, the three masses attached to the string will be set in accelerated motion as is indicated by the arrows. The acceleration of these masses will be that given by the equation (2) in the figure. The downward force on A is always the tension in the string. During the accelerated motion the tension is the weight of M, namely Mg, plus the accelerating force on M, namely Ma, where g is the acceleration due to gravity. This is shown by equation (3).

Since the downward force on A is greater than Mg, the left end of the balance beam will go down, thus showing qualitatively that it requires a force to accelerate a mass. The force which must be added to the weight of M-below-J in order to restore the balance, is the difference between the force now downward on A and the weight of M-on-J. This force, the weight of w, namely wg, is given by equation (4). The mass w which must be added to the scale pan attached to J, is given by equation (5). If the beam is balanced and the apparatus is arranged as shown in the figure, it will retain its equilibrium position. This shows that the force necessary to accelerate M-below-A upwards is exactly equal to the weight of w. Thus this apparatus allows a quantitative measurement of the force necessary to accelerate a mass.

If M-below-A is allowed to accelerate downward by removing a mass M from M-below-C, it is easily seen that, to maintain equilibrium, a mass must be removed from M-below-J since the tension in the string is the weight of M-below-A minus the force necessary to accelerate it downward. The mass which must be removed will be given by an equation like (5) except that the plus sign is changed to minus.

In the first model of the machine which the writer constructed, the beam was 20 inches long, the wheels 1¾ inches in diameter, and the axles ⅛ inch in diameter (should have been made 1/16 inch or even less). When each of the large masses was 550 grams, it was necessary to add 30 grams to M-below-C in order to just take care of friction. The torque caused by this friction was balanced by sliding R a little to the left. The equations show that when m is 50 grams, w must be 23.9 grams. When these were added in their respective places, the beam did not move visibly while m moved 2 meters, even though one gram weight would deflect the end of the beam several centimeters. When 30 grams were removed from M-below-C to overcome frictions and another 50 grams were removed so that the system would accelerate in a direction opposite to the arrows in the figure, it was found that the beam would remain in equilibrium when 26.2 grams (given by equations) were removed from M-below-J.

Thus this Poggendorf's Fallmaschine shows both qualitatively and quantitatively that the apparent weight of a body increases when it is accelerated upwards and decreases when it is accelerated downward, or, in general, that it requires a force to accelerate a mass.

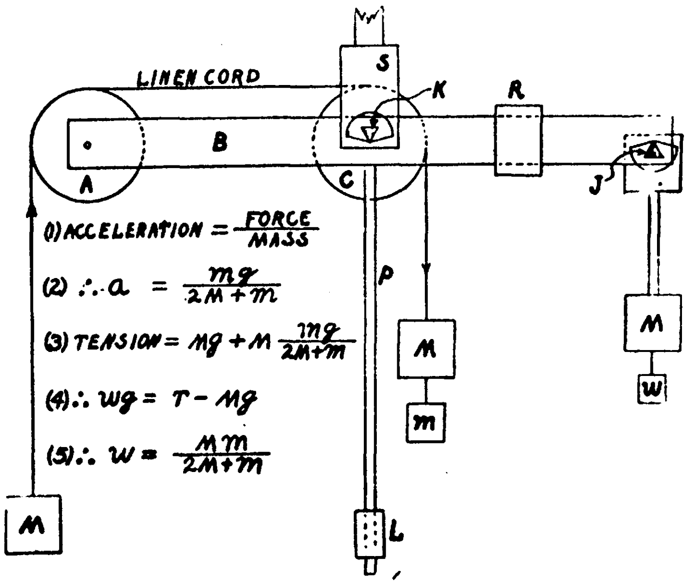

Fig. 1.

Poggendorf's Fallmaschine for demonstrating the apparent change in weight of a vertically accelerated mass.