many cases, but (unless proper precautions have been successfully taken to make this really an Askenasy experiment) the liquid column breaks before the pressure at the top has become negative in sign. Every Askenasy experiment demonstrates suction before any tension is developed and it demonstrates both suction (below) and liquid tension (above) when the pressure at the top is negative.

It is this suction experiment that was referred to by Dr. C. A. Arndt (SCIENCE for May 21, 1926, page 527), who seems to have failed to realize that traction and liquid tension can not begin until after the possibilities of ordinary suction have already been exhausted. This author was apparently not dealing with the Askenasy experiment at all. His "superior results" are to be taken as bearing upon the suction experiment only, being consequently just failures for the Askenasy experiment. Without additional data (barometric pressure, length of water column above the mercury in the system, and bore of tube) even the "greatest total height" given, 28 inches, is not in itself evidence of liquid tension, although the smallness of the difference between this value and the normal barometer reading (about 30 inches for Philadelphia) indicates that the pressure in the top of the system was as low as one or two inches of mercury. Shorter mercury columns of ten or twenty inches, such as Dr. Arndt mentions, surely represent failures as far as the demonstration of tension by the Askenasy method is concerned. From Dr. Arndt's printed statement and also from correspondence with him it is clear that the pressure on the surface of the mercury in the reservoir was the current barometric pressure.

Plant physiology requires as careful thinking as do the physical sciences, and students of plant water relations should be led to distinguish clearly between suction and traction. In the case of suction the elongating or moving column of liquid is under the action of two opposing external forces, one larger than the other but both tending to compress the liquid and shorten the column. In the case of traction also there are two external opposing forces, but both tend to overcome the cohesion of the liquid and stretch the column. In the first case the liquid column is slightly compressed, in the other it is slightly stretched (tension). In suction the liquid is *pushed* up and in traction it is *pulled* up. For a demonstration of suction alone it is not necessary to exercise any special care in setting up the apparatus, but special treatment is generally necessary if any tension or traction is to be developed.

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SIMPLE SEISMIC MEASUREMENTS

THE measurement of earthquake acceleration maxima by observation of the fall of vertical columns was proposed more than forty years ago. The condition that a properly directed horizontal acceleration should be sufficient to overturn a simple rectangular parallelopiped was stated by Professor C. D. West as $a = gb/h$, where h is the height and b the breadth of the paralellopiped, and g is the gravitational acceleration. This relation results at once if one equates the inertial moment about a lower edge of the parallelopiped to the gravitational moment about the same edge. By observation after a quake of the status of a number of parallelopipeds having different ratios b/h an estimate of the magnitude of the maximum acceleration was to have been obtained. But upon testing this method by experiment Milne[1] and Omori[2] found West's formula to be inapplicable to earthquake-like accelerations. Discrepancies as high as 35 and 40 per cent., some positive and some negative, were recorded.

There seem to have been two reasons for this disagreement. The acceleration of West's formula—or rather any acceleration in excess of it—although undoubtedly sufficient to *start* the overthrow will not bring it to completion if the duration of the acceleration be too brief. Seismic accelerations are not constant accelerations but are of an alternating nature and may rise to maxima much higher than that expressed by the above equation and yet die away so quickly that the complete overthrow does not take place. On the other hand, the alternating character of the acceleration may in some cases result in the upset of the parallelopiped through the development of resonant oscillations, even though West's acceleration is never attained. In this case the elasticity of the paralellopiped and of its foundation play an important part. These errors, though opposite in sense, can not be expected to annul each other, and a discrepant result, difficult at present to predict, will in general remain.

West's equation, in short, does not apply to the case of an object overturned by an acceleration of alternating or oscillatory character because it was never formulated to fit such conditions. It correctly defines the minimum acceleration, however attained, at which the object will start to turn over. But only for special cases, such as that of a constant acceleration, does the formula state the acceleration competent to complete the overthrow.

The theoretical treatment of an object overthrown by simple harmonic motion does not appear to have been presented. Galitzin dismisses the matter with the observation that the problem offers real difficul-

[1] J. Milne, Trans. Seis. Soc. Japan, Vol. 8, 1885.
[2] J. Milne and F. Omori, *Seis. Journ.*, Vol. 1, 1893.

ties. The difficulties are substantially reduced however by the assumption that the stability is such that the object rotates through only a small angle ($\tan \vartheta = \vartheta$) before coming to a position of instability. This assumption fortunately does not impair the application of the results to actual earthquake accelerations up to the intensity ranked by Cancani as "Very disastrous." The geometrical form of the object considered is of no real importance and we may drop all restrictions of this kind and assume only a rigid body stably supported by a horizontal axis somewhat lower than its center of mass, and a brace or stop of some kind which prevents rotation under the action of gravity. The object thus described will be referred to as a bar. The angle made by a vertical and the perpendicular dropped from the center of mass of the bar upon the axis of rotation will be called ϑ.

Now it may be shown that the bar will just be thrown down by a horizontal simple harmonic motion directed at right angles to its axis if the maximum acceleration of the motion has the value

$$a = g\,\vartheta\sqrt{1 + \frac{4\pi^2 R^2}{g\,L\,T^2}}.$$

In this equation R is the radius of gyration of the bar, L the distance from the center of mass to the axis of rotation and T the period of the oscillation. The derivation of the equation is too lengthy to be appropriately presented here and it must suffice to state that it has been deduced by rigorous methods and completely verified by experiment.

The experimental work was conducted upon an oscillating table capable of horizontal simple harmonic motion of adjustable period and amplitude. Every variable quantity represented in the above equation was varied through wide limits, and of over five hundred observations every one conformed to the equation within the leeway of two or three per cent., which the uncertainties of observation permitted.

It is worth noticing that with an infinitely long period of oscillation—and therefore with constant acceleration—the equation reduces to $a = g\,\vartheta$, which is West's formula stated in a slightly different way.

A series of similar bars of suitable form, mounted at a variety of angles of inclination so that an earthquake would cause some to fall and leave others standing, would yield important information about the nature of the oscillatory horizontal movement. But it is evident from the equation that a knowledge of the critical angle dividing the fallen from the standing bars will not in general suffice to determine the maximum acceleration, since the acceleration is a function both of this angle and of the period of oscillation. The influence of the period can only be suppressed by making the whole second term under the radical sign a small quantity, even for short periods. Experiment shows that this may be done by a suitable choice of the form and dimensions of the bar, so successfully, at least, that for all oscillations with periods greater than one fourth of a second the maximum acceleration is fully determined by the critical angle, with an error which can not be greater than six per cent. and which is much less in nearly all cases. It is probably not worth while at present to strive for greater accuracy at this point, since the errors resulting from the assumption that the earth motion is simple harmonic have not been investigated.

The problem may be approached in another way. Referring again to the equation one sees that a knowledge of the critical angle, as obtained by observing a given set of bars, gives an equation in which a and T alone are unknown. From a second set of bars, different from the first in R or L, another critical angle is observed, giving another relation between a and T. The two equations are independent and together suffice to determine both a and T. With the acceleration and period known the corresponding amplitude is of course readily computed. These determinations are subject to three errors only. The first is the error in determining the critical angles; it may be made as small as desired by the use of a larger number of bars. The second is the error involved in the assumption that ϑ is small; this is entirely negligible for quakes of small intensity and rises only to about one per cent., with very disastrous quakes. The third error is that of the assumption that in the neighborhood of the maximum acceleration the earth motion is simple harmonic. Assumptions of this kind have often been made, but never, so far as known, critically investigated. It is impossible at the present time to make a numerical statement of the exactitude of this assumption, but its validity becomes of less and less importance for present purposes as the radius of gyration of the bars is diminished. It appears probable to the writer that errors of this sort in the determination of maximum acceleration can be kept below five per cent.

It appears possible therefore to make important earthquake measurements with extremely simple and inexpensive apparatus. Through the courteous cooperation of Dr. T. A. Jaggar instruments are soon to be located upon the island of Hawaii, a region which by reason of frequent local quakes should serve admirably as a proving ground for seismometrical devices. A more complete paper upon these subjects will be published in the near future.

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