portion is to exceed the value for ordinary rockets, which is about $^1/_5$. This action consists in the loading and firing of a number of charges successively in the same combustion chamber.

The results of work upon this feature, to date, have been the development and experimental demonstration of a simple and light multiple charge apparatus, firing a few cartridges and travelling straight. In order to complete the development, it is necessary to adapt the apparatus to fire a large number of cartridges, and to make the parts, exclusive of propellant, sufficiently light. Work on increasing the number of cartridges is in progress.

In order to complete the development with a minimum of expense, the perfecting of details should be carried out only insofar as is necessary in order to produce an inexpensive apparatus. The only expense of maintenance will be a new magazine for each ascent.

In any case, the time required to reach the 10 km. level should be of the order of 20 seconds, if the retardation due to air resistance and gravity is minimized.

As an illustration of what should be possible with an apparatus developed in this way, it may be said that, using as a basis for the estimate a velocity of ejection of 5,500 ft./sec., which is easily obtained, a rocket weighing of the order of 11 lbs. initially and 6 lbs. at the highest point would be needed in order to send instruments weighing one pound to the 10 km. level.

NOTE ON A PNEUMATIC METHOD OF MEASURING VARIATIONS OF THE ACCELERATION OF GRAVITY[1]

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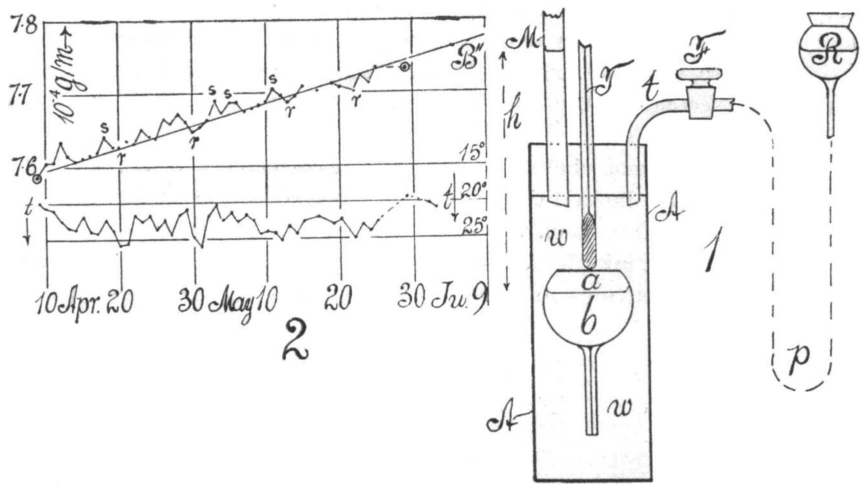
Communicated June 22, 1920

1. *Introductory.*—Some years ago I made an extended series of experiments[2] on the diffusion of gases through water; the gas in this work was imprisoned in a cartesian diver, and the very sensitive conditions under which the diver floats at a given level were made the criterion of measurement.

Inasmuch as such experiments consist virtually of a comparison of weights with the forces derived from air pressures, it must, therefore, be possible to obtain the acceleration of gravity in terms of these pressures, just as in another place I shall describe interferometer experiments made to evaluate the changes of g in terms of torsion. It will not, of course, be possible to determine g absolutely in this way because so little air is used; but it was hoped that the changes of g, in a proper environment would be determinable with some precision. Quite apart from this specific purpose, however, the long range experimental data are of varied interest.

2. *Apparatus.*—The chief difficulty with the experiment at the outset seems to be the elimination of loss of gas by diffusion. This, in the case of a cylindrical diver, open below, amounted in the experiments cited, to 0.41% per day. It would not, therefore, be long before the whole of the gas would be lost. To avoid this, two resources suggest themselves: (1) to place the diver about midway between two layers of air, one below and the other above it; and (2) to provide the diver with a long slender neck below, precisely what was to be avoided in cases of diffusion. I shall not describe the forms of apparatus in which the first precautions were taken, as they proved to be unavailable; nor any of the correlative forms with the diver sheathed within a completely submerged cylindrical tube, nearly closed. The results so obtained were no better than those



FIGS. 1 AND 2

found with the extremely simple apparatus, figure 1. The swimmer being here lighter than water, *AA* is the standglass, wholly filled and *a*, *b*, the swimmer held down at a definite level by the thermometer *T*. *M* is a water manometer for registering the pressure excess at which flotation just occurs at the given level. Pressure is applied by aid of the small water reservoir, *R*, communicating with *AA* by the tube *t* with the stopcock *F*, and the flexible pipe *p*, the whole system *t F p R* being full of water. To make an observation, *R* is raised sufficiently and clamped. The cock *F*, is now slightly opened, until the swimmer just begins to sink. The head of water, *h*, is then read off at *M*. This adjustment may be made to a fraction of a millimeter of water. The apparatus admits of observation in an agitated environment.

The diver, which to be sensitive must be as light as possible (thin stem preferable), consisted of a bulb 4.5 cm. in diameter and a stem 4 cm. long and about 2 mm. in diameter. The rate of loss would be decreased by diminishing this diameter further; but it is by no means proportional to the sectional area.

3. *Equations.*—If M is the mass of the diver, m that of the air contained at the absolute temperature τ and pressure $h + (H - \pi)\rho_m/\rho_w$ in centimeters of water (h being the incidental water head, figure 1, H the residual mercury head, and π the vapor pressure in centimeters of mercury, ρ_m, ρ_w, ρ_g, the densities of mercury, water and glass, all read off at τ), we may write for the gravitational acceleration, g:

$$g = \frac{Rm\tau}{[h + (H - \pi)\rho_m/\rho_w][(1 - \rho_w/\rho_g)M + m]}. \qquad (1)$$

The first term in the denominator is to be multiplied by ρ_w at τ, to get the water head at 4° C.; the second term to be divided by ρ_w to get the volume of the air bubble. These reductions, therefore, cancel each other. Mercury, water, and air are necessarily at the same temperature, at least in a proper installation of apparatus.

Thus it follows that variations of g are determinable with the same accuracy as τ and H. The former being of the order of 290°, 0.03° C., must be guaranteed if g is to be correct to 10^{-4}. Furthermore, H, which is over 1000 cm. of water, must be read to 1 millimeter for the same accuracy. Both of these requirements are moderate. By tapping the tables from below, the swimmer is slightly separated from the thermometer above, and the degree of flotation may thus be estimated with great precision, by the speed with which the swimmer rises again into contact. An accuracy of 0.01% in g may thus be expected, provided m is adequately constant. This paper indicates to what degree this may be insured; for in a heated room, in winter, with very variable temperatures, the test is extremely severe.

The absolute determination of g is dependent on the value of m. To measure this, large swimmers would be needed such as would make the apparatus too cumbersome. With regard to small quantities or small changes of the quantities ρ_m, ρ_w, etc., equation (1) may be stripped of its less important terms and written in an approximate form. The corrections are then found by logarithmic differentiation.

4. *Observations.*—Figure 2, curve B, contains the most complete series of observations made with this apparatus, g/m in ten thousands, being shown in its variations within a lapse of somewhat less than two months. Readings were made about at noon daily and the corresponding temperatures are given (increasing downwards) in the graph marked t. Corrections for the temperatures, etc., have been applied. As the air content was too small for persistent flotation, the diver was liable to sink at low temperatures, or high barometers, or both (s, in the figure). It is under these circumstances that the irregularities of the curve are usually marked.

In the figure, a line has been drawn through a succession of points which seem to suggest it. For this g/m increases per day (owing to the decrease of m) at a mean rate of $r = 0.00039$, which is equivalent to and air loss of 5×10^{-6} grams per day. Though it was formerly my opinion that the phenomenon could be completely explained in terms of the diffusion of air through water, the cusps (s) and subsequent intervals of relapse (r) when temperature increases, again do not bear this out. The whole is more complicated. The mechanism by which the air loss is brought about is largely solutional. Air is dissolved when temperature falls and is released from solution when temperature rises again. But for this the rate of increase of g/m throughout many months is in all the results remarkably constant and could be allowed for. Only at the beginning of the experiments with a new diver, and owing probably to gas adhering to the glass walls, are these mean rates irregular.

But the solutional effect in question under rapidly varying temperatures is fatal to the purpose for which the experiments were made. Though much of the discrepancy could be removed by placing the whole apparatus in an adequately constant thermostat, the outlook is not encouraging.

[1] Advance note from a Report to the Carnegie Institution of Washington, D. C. The work was done in deference to a request of President R. S. Woodward, that a variety of methods of the kind in question be looked into.

[2] *Carnegie Publications*, No. 185, Washington, 1913.

NOTE ON TORSIONAL MEASUREMENT OF VARIATIONS OF THE ACCELERATION OF GRAVITY BY INTERFERENCE METHODS[1]

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Communicated July 1, 1920

1. *Apparatus*.—These experiments were undertaken to find in how far interferometer methods might contribute to the measurement of changes of g, under conditions in which the pendulum is inapplicable. The apparatus as a whole is a horizontal torsion balance with the deflection readable in terms of the displacement of the achromatic interference fringes. The method developed would be applicable in case of any ordinary chemical balance. The interferometer described admits of moderately rough handling; but it requires a level base, at least during observation. The mirrors are adjusted normally to a vertical plane, as the rays are in this direction.

Torsional weighing, by passing the counterpoise from pan to pan, is in itself a delicate operation when fringes are used. Moreover, the variation of viscosity is particularly large at the beginning. Nevertheless