SIX REASONS FOR THE PROSECUTION OF PENDULUM EXPERIMENTS.

By C. S. Peirce.

1. The first scientific object of a geodetical survey is unquestionably the determination of the earth's figure. Now, it appears probable that pendulum experiments afford the best method of determining the amount of oblateness of the spheroid of the earth; for the calculated probable error in the determination of the quantity in question from the pendulum work already executed does not exceed that of the best determination from triangulation and latitude observations, and the former determination will shortly be considerably improved. Besides, the measurements of astronomical arcs upon the surface of the earth cover only limited districts, and the oblateness deduced from them is necessarily largely affected, so that we cannot really hold it probable that the error of this method is so small as it is calculated by least squares to be. On the other hand, the pendulum determinations are subject to no great errors of a kind which least squares cannot ascertain; they are widely scattered over the surface of the earth; they are very numerous; they are combined to obtain the ellipticity by a simple arithmetical process; and, all things considered, the calculated probable error of the oblateness deduced from them is worthy of unusual confidence. In this connection it is very significant, as pointed out by Colonel Clarke (*Geodesy*, p. vi), that while the value derived from pendulum work has for a long time remained nearly constant, that derived from measurements of arcs has altered as more data have been accumulated, and the change has continually been in the direction of accord with the other method. It is needless to say that the comparison of the expense of the two methods of obtaining this important quantity is immensely in favor of pendulum work.

2. Recent investigations also lead us to attach increased importance to experiments with the pendulum in their connection with metrology. The plan of preserving and transmitting to posterity an exact knowledge of the length of the yard after the metallic bar itself should have undergone such changes as the vicissitudes of time bring to all material objects, was at one time adopted by the British Government. It was afterwards abandoned because pendulum operations had fallen into desuetude, and because doubts had been thrown upon the accuracy of Kater's original measure of the length of the second's pendulum. Yet I do not hesitate to say that this plan should now be revived, for the following reasons:

First, because measurements of the length of the second's pendulum, although formerly subject to grave uncertainties, are now secure against all but very small errors. Indeed, we now know that the determinations by Kater and his contemporaries, after receiving certain necessary corrections, are by no means so inaccurate as they were formerly suspected to be. Secondly, metallic bars have now been proved, by the investigations of Professor Hilgard and others, to undergo unexpected spontaneous alterations of their length, so that some check upon these must be resorted to. To this end the late Henri Ste. Claire Deville and Mascart constructed for the International Geodetical Association a metre ruled upon a sort of bottle of platin-iridium, with the idea that the cubic contents of this bottle should be determined from time to time, so as to ascertain whether its dimensions had undergone any change. I am myself charged with, and have nearly completed, a very exact comparison of the length of a metre bar with that of a wave of light, for the same purpose. Neither of these two methods is infallible, however, for the platin-iridium bottle may change its three dimensions unequally, and the solar system may move into a region of space in which the luminiferous ether may have a slightly different density (or elasticity), so that the wave length of the ray of light used would be different. These two methods should therefore be supplemented by the comparatively simple and easy one of accurately comparing the length of the second's pendulum with the metre or yard bar. Thirdly, I do not think it can be gainsaid by any one who examines the facts that the measurements of the length of the second's pendulum by Borda and by Biot in Paris and by Bessel in Berlin do, as a matter of fact, afford us a better and more secure knowledge of the length of their standard bars than we can attain in any other way. So also I have more confidence in the value of the ratio of the yard to the metre obtained by the comparison of the measurements of the length of the second's pendulum at the Kew observatory by Heaviside in terms of the yard and by myself in terms of the metre than I have in all the

elaborate and laborious comparisons of bars which have been directed to the same end. I will even go so far as to say that a physicist in any remote station could ascertain the length of the metre accurately to a one hundred thousandth part more safely and easily by experiments with an invariable reversible pendulum than by the transportation of an ordinary metallic bar.

A new application of the pendulum to metrology is now being put into practice by me. Namely, I am to oscillate simultaneously a yard reversible pendulum and a metre reversible pendulum. I shall thus ascertain with great precision the ratio of their lengths without any of those multiform comparisons which would be necessary if this were done by the usual method. These two pendulums will be swung, the yard one in the office of the Survey, at a temperature above 60° F., which is the standard temperature of the yard, the other nearly at 0° C., which is the standard temperature of the metre; and thus we shall have two bars compared at widely different temperatures, which, according to ordinary processes, is a matter of great difficulty. The knife-edges of the pendulums will be interchanged and the experiments repeated. Finally, the yard pendulum will be compared with a yard bar and the metre pendulum with a metre bar, and last of all the yard pendulum with its yard bar will be sent to England, the metre pendulum with its metre bar to France, for comparison with the primary standards; and thus it is believed the ratio of yard to metre will be ascertained with the highest present attainable exactitude.

3. Geologists affirm that from the values of gravity at different points useful inferences can be drawn in regard to the geological constitution of the underlying strata. For instance, it has been found that when the gravity upon high lands and mountains is corrected for difference of centrifugal force and distance from the earth's centre, it is very little greater than at the sea-level. Consesequently it cannot be that there is an amount of extra matter under these elevated stations equal to the amount of rock which projects above the sea-level; and the inference is that the elevations have been mainly produced by vertical and not by horizontal displacements of material. On the other hand, Mendenhall has found that gravity on Fujisan, the well-known volcanic cone of Japan, which is about 12,000 feet high, and which is said to have been upheaved in a single night, about 300 B. C., is as much greater than that in Tokio as if it had been wholly produced by horizontal transfer. This conclusion, if correct, must plainly have a decisive bearing upon certain theories of volcanic action. Again, it has long been known that gravity is in excess upon islands, and I have shown that this excess is fully equal to the attraction of the sea-water. This shows that the interior of the earth is not so liquid and incompressible that the weight of the sea has pressed away to the sides the underlying matter. But in certain seas gravity is even more in excess than can be due to the attraction of the ocean, as if they had been the receptacle of additional matter washed down from the land. It is evident that only the paucity of existing data prevents inferences like these being carried much further. On the two sides of the great fault in the Rocky Mountains gravity must be very different, and if we knew how great this difference was we should learn something more about the geology of this region; and many such examples might be cited.

4. Gravity is extensively employed as a unit in the measurement of forces. Thus, the pressure of the atmosphere is, in the barometer, balanced against the weight of a measured column of mercury; the mechanical equivalent of heat is measured in foot pounds, etc. All such measurements refer to a standard which is different in different localities, and it becomes more and more important to determine the amounts of these differences as the exactitude of measurement is improved.

5. It may be hoped that as our knowledge of the constitution of the earth's crust becomes, by the aid of the pendulum investigations, more perfected, we shall be able to establish methods by which we can securely infer from the vertical attractions of mountains, etc., what their horizontal attractions and the resulting deflections of the plumb-line must be.

6. Although in laying out the plan of a geodetical survey the relative utility of the knowledge of different quantities ought to be taken into account, and such account must be favorable to pendulum work, yet it is also true that nothing appertaining to such a survey ought to be neglected, and that too great stress ought not to be put upon the demands of the practically useful. The knowledge of the force of gravity is not a mere matter of utility alone, it is also one of the fundamental kinds of quantity which it is the business of a geodetical survey to measure. Astronomical latitudes and longitudes are determinations of the direction of gravity; pendulum experi-

ments determine its amount. The force of gravity is related in the same way to the latitude and longitude as the intensity of magnetic force is related to magnetical declination and inclination; and as a magnetical survey would be held to be imperfect in which measurements of intensity were omitted, to the same extent must a geodetical survey be held to be imperfect in which the determinations of gravity had been omitted; and such would be the universal judgment of the scientific world.

NOTES ON DETERMINATIONS OF GRAVITY.

By Assistant C. A. SCHOTT.

The conference was invited by the Superintendent of the Coast and Geodetic Survey for the purpose of eliciting an interchange of views respecting the utility and best means of prosecuting pendulum research in the interest of science in general, and with especial regard to the future work of the Coast and Geodetic Survey.

Major Herschel, R. E., having expressed his willingness to favor the meeting with his presence and give it the benefit of his great experience in pendulum work, the time of meeting must be considered extremely favorable.

The following rough notes are offered with a view of inviting discussion on some points considered of importance and interest.

Respecting the question of the utility to geodesy and geology of pendulum work as bearing on the figure and density of the earth, it is sufficiently answered by the resumption of this work in recent years in the leading government surveys conducted in Europe, Asia, and America; but in carrying on these operations different opinions continue to be held as to the best and most economical means both with regard to form of instrument and method of observation.

It may be added that the results already reached are in themselves sufficient to stimulate the further prosecution of the work, since they render it almost certain that still more valuable deductions may be reached.

The pendulum work executed for some years past under the direction of the late Superintendent of the Coast and Geodetic Survey had for its immediate object the study, theoretical and practical, of the best methods available, and to gather the results at various important pendulum stations in Europe, to bring them into strict comparability, and to form a connected system which may be used for combination with similar operations commenced in the United States.

Mr. C. S. Peirce, Assistant, Coast and Geodetic Survey, having brought this work to a close in Europe,* its future prosecution at home now claims renewed attention, both with respect to the economy and efficiency of the plans which it may be desirable to adopt.

The value of the pendulum results depending largely upon their direct comparability and the geographical extent, it would in the first place appear most desirable, in order to form a second and independent connection of the pendulum work executed on the other side of the Atlantic, to swing the American pendulums at the two stations, Washington and Hoboken, just occupied by Major Herschel with the old pendulums belonging to the Royal Society, and to add thereto at least one more American station in order to secure three stations of satisfactory accord between these instruments.

It is, perhaps, the general opinion that differential measures are at present more desirable than absolute measures, since undoubtedly greater accuracy can be reached in the former and a greater number may be secured with the same expenditure; indeed, the determination of the length of a second's pendulum is, in geodesy, of less importance than a knowledge of ratios of times of oscillation of an invariable pendulum swung at stations on a line selected for investigation.

The determination of the length of a second's pendulum is quite a special operation, to be undertaken only at a base station.

While the mean figure of the earth may be considered as tolerably well known from the fact of the close approach of the value of the compression as deducted from purely geodetic operations and

* Mr. Peirce remarked that that work was not yet quite completed.