A Simple Ultra-Centrifuge
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Walcott, of the United States Geological Survey, invited the writer to supervise the preparation of Marsh's four incomplete monographs. The materials were found to consist of over 200 carefully prepared lithographic plates, of drawings and wood engravings, some bibliographies and about one hundred pages of rough pencil notes and memoranda. There was no manuscript; the entire text of the four monographs remained to be written. It was obviously appropriate to assign the Ceratopsia Monograph to John Bell Hatcher, because the discovery and collection of these animals was the greatest single achievement of his remarkable life; he had devoted four arduous years to bringing together these magnificent horned dinosaurs for Yale University and the National Museum. Hatcher entered upon this research in July, 1902, with his usual ardor and thoroughness; on July 3, 1904, when he was stricken down the work was taken up and completed in a most admirable manner by Professor Richard S. Lull, of Yale University; it was published in 1907 as United States Geological Survey Monograph 49.

The next volume, the Stegosauria, was assigned to Mr. Charles W. Gilmore, of the United States National Museum, who began work in 1906 and, although the monograph as originally projected was not finished, he published in 1914, as United States National Museum Bulletin 89, the work entitled "Osteology of the Armored Dinosauria in the United States National Museum, with Special Reference to the Genus Stegosaurus," which covers only the material in the United States National Museum, but which established its author as a leading authority on these armor-plated dinosaurs.

Under the name "The Titanotheres of Western North America," research on the Brontotheriidae was begun by the present writer in the year 1900 and with the masterly aid of William K. Gregory was completed and published as United States Geological Survey Monograph 55 under the full title of "The Titanotheres of Ancient Wyoming, Dakota and Nebraska" in the year 1929.

Meanwhile research on the remaining monograph, the Sauropoda, was independently begun by the present writer about 1902 with Mrs. J. K. Mosenthal and, in 1912, with the aid of Dr. Charles C. Mook, of the American Museum staff. The title of this volume, if the plan for its issue can be carried out, will probably be "The Sauropoda of the World."

The problem of preparing "The Sauropoda of the World" differs radically from the problems involved in "The Titanotheres of Ancient Wyoming, Dakota and Nebraska": first, in the fact that we have little or no antecedent history of this remarkable group. The Sauropoda suddenly flash into being, to our present knowledge, towards the close of Jurassic time, fully formed and widely differentiated into a number of very distinct types, all of gigantic size and well fitted by their long limbs for the world-wide migrations which carried them to every continent, even including Australia. The central problem in the Sauropoda Monograph will, therefore, be the distinction of five or six outstanding generic or sub-family types together with the more or less speculative problem of their origin and the intensely interesting problem of the causes and means of their world-wide distribution and finally their extraordinary explosive extinction. Remarkable additions to our knowledge have been made since the superb Marsh lithographic plates, and very clear diagnoses of Sauropod characters were given by Marsh. Valuable collections have been made principally by the Carnegie Museum of Pittsburgh, by Wortman, Hatcher and Peterson under the direction of Dr. W. J. Holland.

The discovery in East Africa of the magnificent Tendaguru deposits explored by Eberhard Fraas, of Stuttgart, and others have been given preliminary descriptions by Dr. Werner Janensch, Dr. Hans Reck and Dr. J. G. Pompeckj, of Berlin. Dr. F. von Huene, of Tubingen, has recently revised Richard Lydekker's monographic work on the Sauropods of South America. Of great significance is the discovery of scattered remains in the Desert of Gobi by the Central Asiatic Expedition under Andrews and Granger, revealing what may have been the central or ancestral region in which these great animals enjoyed their original evolution. It is planned, now that the Titanothere Monograph has been completed, to renew the researches on the Sauropoda with the attempt of coordinating this great mass of new material with the original ground material made in the discoveries and writings of Marsh and of Cope.

HENRY FAIRFIELD OSBORN

SCIENTIFIC APPARATUS AND LABORATORY METHODS

A SIMPLE ULTRA-CENTRIFUGE

IT is hardly necessary to emphasize the value of the centrifuge to science in general. Its numerous uses in so many fields of experimental investigation have made it almost a necessary laboratory tool. As a consequence of this wide usage considerable energy has been directed toward the development of centrifuges with our modern high speed machines as a result. However, there is still very much to be desired in the way of improvement. Many problems of utmost importance remain unsolved because of the insufficient separating power of our best centrifuges. Among the factors which limit the separating power of the centrifuge are, of course, rotational speed, suitable bearings, strength of materials, troublesome vibrations, and simple means of making the centrifuging continuous. During the last few years we have been engaged in a series of researches that required apparatus for obtaining high rotational speeds. Some time ago we undertook to apply this comparatively simple technique to the centrifuging problem and have obtained such remarkable results that it seems worth while to call the attention of others to its possibilities.

The method of whirling the centrifuge consists in both driving and supporting the rotor by means of a whirling cushion of air. By this procedure the maximum rotational speed is apparently limited only by the molecular speed of air and the strength of the rotating parts. In some of our experiments we have obtained rotational speeds of approximately one half million revolutions per minute and centrifugal forces over a million times that of gravity. The experimental arrangement for obtaining these high rotational speeds is a modification of one used by Henriot and Huguenard (*Comptes Rendus,* 180: 1389, 1925; *Jour. de Phys. et Rad.* 8: 443, 1927). A detailed description of the method of rotation and the ways of measuring the rotational speed have been given previously (Beams, *Review of Scientific Instruments,* 1, 667, 1930) so that only a very brief sketch of this part of the apparatus need be given here.

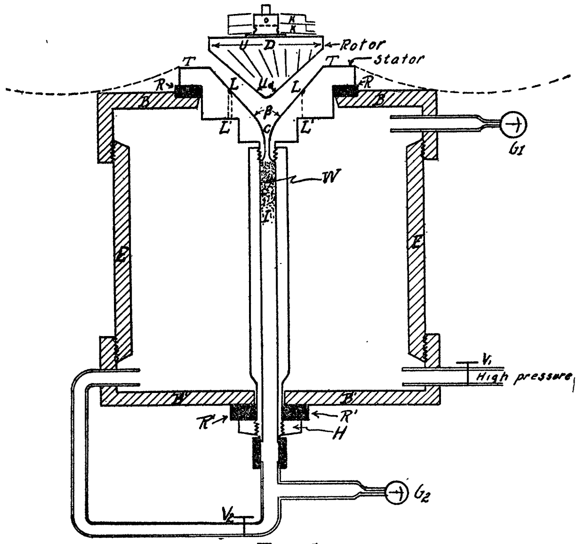

FIG. 1

Referring to Fig. 1, air from a compressor is admitted to the chamber through the valve V_1, until the pressure gauge G_1 registers the desired pressure. V_2 is also opened until G_2 reads the proper pressure, which is found by trial. The rotor is then placed in the position shown in the drawing. The air jets from LL′ and C impinge upon the flutings of the rotor, raise it, and start it rotating. Immediately it seeks a position of stable equilibrium a fraction of a millimeter above the surface of the stator, where it continues to rotate. The air entering through C stabilizes the motion and makes it possible to obtain a greater range of speeds as well as gives a means of easily adjusting for different weights and slightly different shapes of the rotor. In the case of the rotor, or centrifuge proper, the problem immediately arises of how to get the material to be centrifuged in and out without touching or rubbing while the rotor is at full speed. Fortunately this problem can be solved in several ways. If a small amount of material is to be centrifuged the arrangement shown in Fig. 2 is satisfactory. The rotor is filled with the

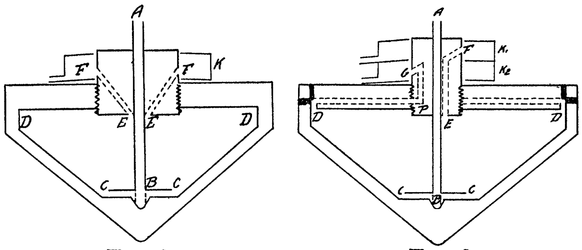

FIG. 2 FIG. 3

liquid and allowed to come to full speed. After the components of the liquid have had time to separate, a somewhat heavier substance, with which the liquid under investigation will not mix, is very slowly dropped into the tube AB (which is slightly larger at B than at A). This forces the lighter fractions out of the tubes EF where it is collected by the cylindrical collector K. Fig. 3 shows a scheme where the centrifuging is continuous. The rotor is first filled through the tube AB then brought to full speed and allowed to rotate for some time. More of the liquid to be centrifuged is then slowly introduced through AB and thus emerges at C. Its heavier constituents move to D and the lighter to E where it is forced up the small hole EF and collected by the collector K_1. The heavier material is forced out through the tube DPG and collected by K_2. There are twice as many tubes as shown in the drawing. MP has a symmetrically placed identical tube while NE (drawn in Fig. 3 at right angles to its real position) also has a symmetrically placed tube to keep the centrifuge in balance. The distance of the tubes PG from the axis of rotation and the height of its opening depend upon the approximate ratio of the densities of the substance to be separated, so it is necessary to design the rotor specially for each ratio of densities. It will be recalled that the practical separating power of a centrifuge depends not only upon the maximum magnitude of the rotational speed but upon the radius of the rotor as well. It is found desirable to make the peripheral velocity as large as possible. Fig. 4 shows an arrangement that

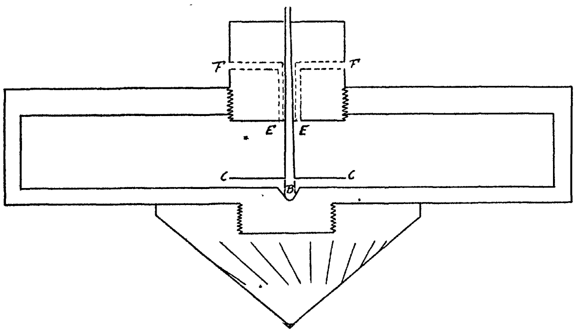

FIG. 4

has some advantage and is very stable. The size of the rotor can be varied over wide ranges. We have used them, for example, from 1 cm to 10 cm in diameter, but the size apparently is not restricted. Peripheral speeds of over 3×10^4 cm per sec. have frequently been attained. A convenient size one inch in diameter made of steel will rotate, when loaded with water, 3,500 revolutions per sec. with the compressor giving only about 1,200 cubic inches of air at a pressure of 100 lbs per square inch above one atmosphere, per minute. For this the angle of the stator $\beta = 91.5°$ and the angle of the rotor $\alpha = 103°$. The 8 holes LL′ were drilled with no. 73 drill.

By adjusting the air pressure the speed of revolution can be varied over wide ranges. The speed, however, remains remarkably constant when the pressure is held constant. Another striking thing is the absence of vibrations in the rotor when filled with a liquid and the consequent reduction of stirring or remixing to a minimum. The theory of separation by centrifuging should, therefore, hold with good approximation.

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A METHOD FOR COMPARING GROWTH RATES BY MEANS OF A PROTRACTOR

IN growth studies on plants and animals, the investigator, in his examination of the data, wishes to compare not only the growth increments, but also the *rates* of growth. The former may be done by the usual graphs, plotted directly from his records, but when he is contending with large amounts of data the numerous calculations of growth rates are time-consuming and become tedious. The writer has employed a simple and rapid method for the inspection of growth rates directly from the increments graphs. Although the method is not exceedingly accurate, it has proven to be of considerable aid in the general study of growth data.

The procedure is as follows: The customary growth increment graphs are plotted upon standard coordinate paper, being careful to locate each point accurately and sharply, and, in any series to be compared, the distances along the abscissa and ordinate allotted to the units of time and growth must remain constant throughout all sheets of graphs.

The rate of growth is the *slope* of the graph between any two points or observations. The value of this slope in degrees is easily determined by means of an ordinary transparent protractor. One has simply to place the point of origin of the protractor exactly upon one point along the graph, and then to rotate the protractor until its basal axis is directly over the point marking the next observation. The value of the slope between these points is read from the protractor over a line which is the continuation of the ordinate of the first point selected. This value, for convenience, is written beside the particular interval of the graph measured. Unfortunately, for this work, protractors are so numbered that the "90°" mark is at the top and the "0°s" are to the right and left at the bottom, with the result that, the more rapid the growth rate, the smaller is the indicated angle corresponding to the slope. To rationalize this, one may subtract from 90 degrees the value found, and then use the complimentary angle. It is better, however, to renumber the protractor so that

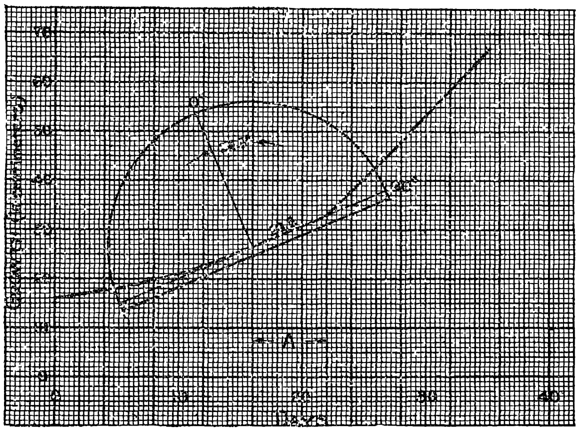

FIG. 1

"0°" occurs at the top, and "90°" at the bottom to the right (the first quadrant only is used). Fig. 1 shows a growth increment graph with protractor in position for measuring the slope of interval "A."