GEORGE HOWARD DARWIN.

George Howard Darwin, the second son of Charles Darwin, was born at Down, Kent, on July 9, 1845. He received his school education at the hands of the Rev. Charles Pritchard, afterwards Savilian Professor of Astronomy at Oxford, entered Trinity College, Cambridge, as a Scholar, in 1864, graduated as Second Wrangler in 1868, and was elected a Fellow of Trinity in the same year. In 1874 he was called to the Bar, but soon afterwards returned to Cambridge and began the long course of investigations in mathematics and astronomy which made him famous. In 1883 he was elected to the Plumian Professorship of Astronomy and Experimental Philosophy, in succession to James Challis, and continued to hold the Chair till the time of his death, which took place on December 7, 1912. He was re-elected Fellow of Trinity, as professor, in 1884, and was married in the same year. He joined the London Mathematical Society in 1868, and some of his earliest papers are published in the *Proceedings*.

The thread which runs through Darwin's researches and renders them a coherent whole is the design of applying mathematical analysis, supported by arithmetical computation, to develop a reasoned cosmogony—a physically intelligible history of the earth, the earth-moon system, and the solar system. The dynamical causes and effects of geological change, the modifications of rotational speeds, mean motions, eccentricities, inclinations, and distances in the earth-moon system and the solar system that can have been brought about by the agency of tidal friction, the conditions for the breaking up of a gravitating fluid mass in rotation as throwing light on the nebular hypothesis and alternative hypotheses, the theory of a swarm of meteorites simulating a gas by collisions, the possible condensation of meteorites to increase two pre-existing nuclei and the determination of localities in which they could escape capture and go to form other nuclei, as offering a possible explanation of the distances of the planets from the sun: these are the main subjects of his work. Naturally there were by-paths. Geological dynamics requires some hypothesis as to the internal constitution of the earth, and Darwin's calculation of the actual fortnightly tide contributed in no small measure to establish the doctrine of the rigidity of the earth. To the same domain belong his design of a bifilar suspension to measure the lunar deflexion of gravity, his reports on observed earth movements, and his papers on " The Stresses produced in the Interior of the Earth by the Weight of Continents and Mountains," and on "The Dynamical Theory of the Tides of Long Period." The theory of tidal friction required an analysis of the tide-generating potential into constituent terms, each proportional to a spherical surface harmonic and to a simple harmonic function of the time, and a provisional development of such an analysis, sufficient for the purpose in hand, was given in the paper on "The Precession of a Viscous Spheroid and the Remote History of the Earth" (1878). When, under the influence of Lord Kelvin, the task of developing a complete analysis and utilizing it for tidal prediction was undertaken by a Committee of the British Association, the work fell to Darwin. He did it thoroughly. His analysis, printed in *Brit. Assoc. Rep.* 1883, is a masterpiece of lucidity, and his final results were put in such a form that comparatively unskilled persons can use them to predict the tides of a port in their most intricate details. Incidentally, as it were, he thus became the greatest authority on the tides, contributing comprehensive articles upon them to the *Admiralty Scientific Manual* and the *Encyclopædia Britannica*, delivering a course of lectures concerning them at Boston, U.S.A., afterwards published as a popular treatise, now in its third edition, and writing the greater part of the article devoted to them in the *Encyclopädie der Mathematischen Wissenschaften.*

The theory of tidal friction was developed in a series of memoirs published in the *Philosophical Transactions of the Royal Society* between the years 1878 and 1881. In these the earth is regarded as a nearly spherical body composed of a material which reacts both by elasticity and by viscosity, the latter property involving the requisite degradation of energy, so that the tidal friction considered is internal friction within the elastico-viscous material distorted by tide-generating forces. In accordance with this supposition, the history of the earth-moon system is traced backwards in time until a critical stage is reached in which the period of rotation of the earth was about five and a half of our present hours, the moon was distant but a few thousand miles from the surface of the earth, and the earth always turned the same face to the moon. Darwin did not hesitate to draw the inference that the moon was once part of the earth and became detached from it, not in the form of a ring as in Laplace's nebular hypothesis, but as a globe. He pointed out that his theory would account effectively for the present relative lengths of the day and month, the inclination and eccentricity of the lunar orbit, the obliquity of the ecliptic, and the fact that the moon now always presents the same face to the earth. He further investigated the extent to which tidal friction can have been a cause of change in other members of the solar system, and found that, except in the unique system of earth and moon, a planet attended by a single satellite of relatively large mass, the effect would be insignificant. These memoirs on tidal friction constitute the work by which Darwin is best known. He himself has declared that it was inspired by a conversation with Lord Kelvin on the subject of the early paper on "The Influence of Geological Changes on the Earth's Axis of Rotation" (1877), for which Lord Kelvin had acted as referee.

The inspiration of the most important work on figures of equilibrium of rotating fluid came from the famous memoir of Poincaré, "Sur l'équilibre d'une masse fluide animée d'un mouvement de rotation" (1885). A mass of homogeneous gravitating liquid, rotating slowly about an axis passing through its centre of gravity, takes the form of an oblate spheroid. If the angular velocity increases gradually, the figure becomes more and more oblate until a critical stage is reached beyond which it can no longer be an ellipsoid of revolution, but becomes an ellipsoid with three unequal axes. If the angular velocity is increased sufficiently, the ellipsoid tends to pass into a surface which has been described as "pear-shaped." The supposition that further change might result in the rupture of the pear by shedding the stalk end at the waist is inevitable, and suggests a previously unsuspected possibility in regard to the origin of planetary systems and double stars. Darwin determined to probe this suggestion. Realizing that he must needs use ellipsoidal harmonic analysis, and finding that the current formulæ relating to ellipsoidal harmonics were not well suited to arithmetical computation, he proceeded to develop the theory of these functions in a fashion appropriate to his purpose, and to apply them to the problem of determining the conditions of stability of the pear-shaped figure. These researches were published in a series of memoirs printed in the *Philosophical Transactions* between the years 1901 and 1903. His conclusion that the pear-shaped figure is stable has been disputed by Liapounoff, and the matter has not yet been settled satisfactorily. A subsequent paper on "The Figure and Stability of a Liquid Satellite" (1906) was devoted to the extension and verification of the work of E. Roche, according to which a planet and satellite can be too close together for the figure of either of them to be an ellipsoid. The determination of the figures of both when within this limit offers a problem of great interest in its bearing on questions of cosmogony, and, if Darwin did not solve it, he has gone further than any one else towards obtaining a solution.

But the perennially fascinating problem which seems to have dominated his attention in the intervals allowed by other occupations was the problem of three bodies. In the simplest form of the problem known as "the restricted problem of three bodies" two gravitating particles, say a sun and a planet, revolve in circles around their common centre of gravity, and a third particle, too small in mass to affect this regular revolution, moves in the plane of motion of the first two. It may ultimately collide with one of them, or it may revolve in an orbit as an inferior planet, or as a superior planet, or as a satellite, or its motion may change from that answering to one of these descriptions to that answering to another. The integration of the equations of motion, even for the restricted problem, has hitherto defied mathematical analysis. But G. W. Hill showed in 1878 how to construct a particular solution in which the third particle describes a periodic orbit as a satellite. This result was the starting point of Darwin's work. Observing that what was required was essentially the determination of a trajectory in which the curvature was known as a function of the position and the direction of motion, he set about a systematic search for periodic orbits by a step-by-step method of approximate integration. The stronghold, impregnable to analysis, was to be besieged by arithmetic. Some years later Poincaré published his remarkable researches on the problem of three bodies, emphasizing *inter alia* the importance of periodic orbits, but these researches did not inspire the work of Darwin who had for years been occupied with the problem. His results were ready for publication in 1897, when they appeared in the *Acta Mathematica*, t. 21, in a famous memoir on "Periodic Orbits." Others promptly took up the problem, among them notably S. S. Hough, and his discussion led Darwin to further investigations which were published some years later. The courage and perseverance required for this work are perhaps not less conspicuous than the interest of the results obtained.

The distinguishing quality that manifests itself in all Darwin's writings is an immense patience. He did not seek after short cuts or elegant methods, and would sometimes reach general conclusions by examining the numerical details of multitudes of special cases, expending upon his calculations a labour and care that would appal most mathematicians. His papers have been republished by the Cambridge University Press in four massive volumes. Yet, in spite of weak health and continual occupation with research, he found time to fill with distinction several official and quasi-official positions. A few examples of this kind of activity must suffice. Soon after his return to Cambridge he was nominated by the Royal Society a member of the Meteorological Council, and at a later date, when the Council was re-arranged as a Committee under the Treasury, he became one of the two representatives nominated by the Royal Society to serve on that body. He succeeded Sir G. G. Stokes as adviser of the Indian Government and referee in regard to the

Indian survey, and when the International Geodetic Association was established he was appointed by the Foreign Office as the representative of Great Britain. When the triennial meeting of the Association was held in London in 1909, he acted as Vice-President, and had a large share in organizing the gathering. He was President of Section A of the British Association in 1886, when he took as the subject of his address "Geological Time," and was elected President of the Association in 1905, the year in which he received the title of K.C.B. He devoted his address on this occasion to the theme of evolution in the physical universe. When it was decided to hold the fifth International Congress of Mathematicians in Cambridge in 1912, he became chairman of the organizing committee, and was subsequently elected president of the Congress. The success of the meeting was due largely to his initiative and to the tact with which he discharged the duties of the chair. Although such offices as this are sometimes supposed to be of the nature of compliments, they involve the expenditure of time and trouble in mastering the details of business and in preparation for the inevitable speech-making in which it is most essential not to say the wrong thing. Many honours of a less responsible kind were conferred upon Sir George Darwin. He was the recipient of honorary degrees from many Universities in Europe and America, and became a corresponding member of many of the most notable foreign academies and learned societies, but it is said that there was no distinction which he appreciated more highly than the award to him in 1911 of the Copley Medal by the Royal Society. It was well earned. Few men have attempted so much. Rare indeed are those endowed with the faith, the courage, the insight, the industry, and the sobriety of judgment that issue in such solid achievement.

A. E. H. L.