THE ORIGIN OF THE PLANETESIMAL THEORY*

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Abstract. T. C. Chamberlin suggested in 1897, on the basis of geological and climatological arguments, that the planets were formed by accretion of cold solid particles. With F. R. Moulton he developed convincing arguments against the Laplace nebular hypothesis and published a comprehensive 'planetesimal theory' of the origin of the solar system in 1905. The Chamberlin-Moulton theory has current as well as historical interest.

Several contemporary accounts of the formation of planets are based on the 'planetesimal theory' proposed at the beginning of the 20th century by Thomas Chrowder Chamberlin (1843-1928) and Forest Ray Moulton (1872-1952). They argued that gases extracted from the Sun by the action of a passing star first cooled and condensed to solid particles and then slowly accreted to form planets. Gravitational contraction would supply heat at a later epoch appropriate to the development of life, but not rapidly enough to produce significant large-scale melting of the Earth at any time.

Historically the Chamberlin-Moulton theory was introduced as a replacement of the Laplace 'nebular hypothesis' which was generally accepted throughout most of the 19th century. Laplace had suggested that a rotating Sun with a greatly extended atmosphere would spin off rings of hot gas as it shrinks, and these rings would condense to molten balls which eventually cool to planets having solid crusts. This theory seemed to fit well with geological evidence; some rocks had apparently been formed at high temperature, and mountain ranges could be attributed to the crumpling of a solid crust settling into a liquid interior that contracted as it cooled. Volcanic eruptions, and the steady increase of underground temperature with depth, suggested that the interior is still hot enough to be mostly liquid.

The nebular hypothesis was the foundation of a grand scheme of cosmic evolution, from the primordial gas to the development of organic species on earth. Such schemes were being discussed even before the publication of Darwin's *Origin of Species* in 1859, and provoked the same religious objections that were later raised against Darwin's theory. From the scientific viewpoint the main difficulty with the scheme was that the only phase that could be worked out quantitatively, the cooling of the Earth from its initial molten state, gave results that seemed to contradict geological evidence. Lord Kelvin, assuming uniform cooling of a solid sphere with no internal heat sources, estimated that the age of the Earth since its solidification was no more than 10 or 20 million years. Geologists on the other hand thought that hundreds of millions of years had been occupied by the slow

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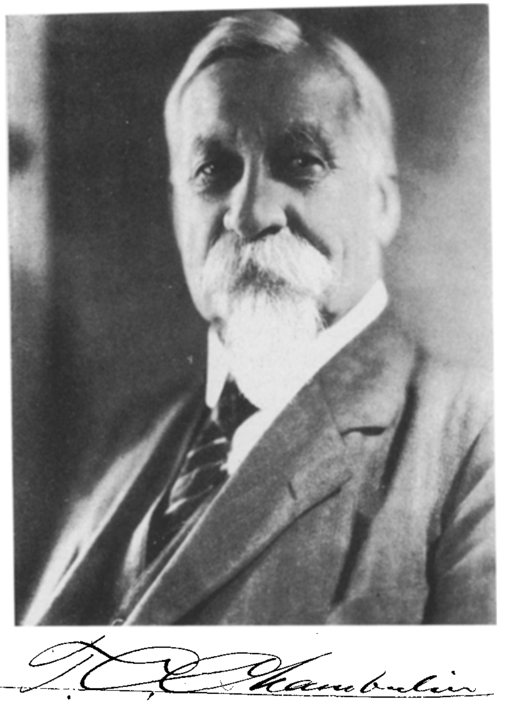

T. C. CHAMBERLIN
Source: *Biographical Memoirs of the National Academy of Sciences*, volume 15 (1934) facing page 305.

processes they studied, and Darwinian evolution was also believed to require a similar time scale. Kelvin was not flatly opposed to evolution (as is sometimes stated) but he did object to the random character of natural selection. (See Brush, 1977, for a discussion of this debate.)

T. C. Chamberlin was already in his fifties when he began to develop his planetesimal hypothesis, and published his complete theory at age 62. He was a geologist whose interest in glacial rock formations had led him to consider theories of the cause of the ice ages based on hypotheses about changes in the carbon dioxide content of the Earth's early atmosphere. It had been suggested that the Earth started with a dense hot atmosphere rich in carbon dioxide, but Chamberlin concluded from G. J. Stoney's application of the kinetic theory of gases that such a state is unlikely. At the high temperatures required by the nebular hypothesis for the primeval Earth, the atmospheric gases would have been dissipated into space. A cold origin of the Earth was needed to account for retention of the gas up to the present time.

In looking through the literature on the nebular hypothesis, Chamberlin found that the planets had sometimes been supposed to have formed by accretion of solid particles – the so-called 'meteoritic theory' – rather than by condensation of hot fluid balls. But the meteoritic theory suffered from one fundamental defect: solid particles revolving in circular Kepler orbits around the Sun would have linear speeds that decrease with distance from the Sun. Planets formed by combining particles in neighboring orbits would therefore have retrograde rotation, whereas most of the known planets were thought to have direct rotation.

Chamberlin argued that this objection could be removed by taking account of the eccentricity of the particle orbits and the variation in their speeds at different parts of their paths. Collisions between particles in different orbits would occur in such a way that the particle in the outer orbit would be in the more perihelion portion of its orbit while the particle in the inner orbit would be in the more aphelion portion of its orbit; since the speed near perihelion is greater, the particle in the outer orbit will on the average have higher speed than the one in the inner orbit, and the body formed by accretion from such encounters will have direct rotation.

It would be interesting to know whether Chamberlin's argument is valid. Most astronomers who have examined it seem to be dubious, but calculations by R. T. Giuli (1968) give it some support.

In order to defeat the nebular hypothesis on its own territory, Chamberlin recruited a young astronomer, F. R. Moulton, at the University of Chicago (where Chamberlin was head of the Geology Department). Together they put together a fairly convincing case, relying on arguments such as the fact that the Sun's angular momentum is too low for it to be the end result of the Laplacian process. (Chamberlin, 1900; Moulton, 1900). But they went too far, at least from the modern viewpoint, when they subsequently not only rejected the nebular hypothesis but postulated a stellar encounter to account for the origin of the solar system (Chamberlin, 1905; Moulton, 1905). Such encounter theories were popular in the first three decades of the 20th century, culminating in the 'tidal' theory of J. H. Jeans and Harold Jeffreys. Jeffreys, however, rejected what Chamberlin considered the essential feature of his theory, the formation of planets from cold solid particles, and returned to the 19th-century idea that the Earth was formed as a hot liquid ball. The Chamberlin-Moulton theory came to be regarded merely as a crude precursor of the Jeans-Jeffreys theory, much to the annoyance of Chamberlin and Moulton. Later, when the Jeans-Jeffreys theory was rejected, the details of the Chamberlin-Moulton theory were forgotten, though the term 'planetesimal' survives in some modern theories.

I have discussed in detail elsewhere the role of Chamberlin and Moulton in the changes of cosmogonical thinking between 1895 and 1925, including their disagreements with Jeans and Jeffreys (Brush, 1976), and Susan Schultz (1976) has given a comprehensive account of Chamberlin's life and work.

The origin of the planetesimal hypothesis was important in the history of science because it involved a major change in astronomical theory motivated by arguments from geology, climatology and the kinetic theory of gases, and the (temporary) triumph of 'naturalistic' reasoning – as Chamberlin described his approach – over mathematical methods. It was also a bold American attack on the views of prestigious British and French theorists, providing a counterexample to the frequent assertion that Americans were weak in abstract science during the 19th century. Contemporary cosmogonists may still find some interest in the original version of the planetesimal theory, and in particular Chamberlin's argument that accretion produces direct rotation still needs a satisfactory proof.

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