RECENT PLANETARY PHYSICS AND CHEMISTRY

R. Smoluchowski*
Princeton University
Princeton, New Jersey 08540
Present address: University of Texas,
Austin, Texas.

ABSTRACT

Within the last few years considerable progress has been made in our knowledge and understanding of the origin of planets and of the structure of their interiors and atmospheres. Some of these advances including Venera and Viking results are summarized for all the planets (except Earth) with accent on those facts which seem amenable to theoretical analysis. Only the minimum background information is added for completeness. (The results of the 1978-79 Mariner-Venus Orbiter, Pioneer 11 and Voyager 1 and 2 missions as well as other observations are very briefly summarized in appropriate addenda).

I. Introduction

Three factors contributed to the recent rapid development of our understanding of planets: a) progress in the theory of the formation of planets and of their satellites from the primitive solar nebula, b) the large number of new data obtained from terrestrial and spacecraft observations and c) availability of much better equations of state for the planetary interiors based on experiment and on theory. Only highlights of these developments are mentioned in this survey and the choice is admittedly very subjective. The stress is placed on physics and chemistry of the planets rather than on descriptive morphological and geological aspects of their surfaces. The inner planets are rather briefly treated but recent data obtained from Venera and Viking missions are included. Jupiter occupies most of the space since many of its basic properties can be derived from first principles so that, from this point of view, it is the best known of all planets. (Many new observations and theoretical results made within the last year or two necessitate corrections and additions. These were introduced in a few places in the text and at the end of the appropriate sections.)

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2. Origin of Planets

A study of the formation of planets from the primitive solar nebula requires taking into account numerous processes: accretion of matter, various gravitational instabilities which can lead to the formation of the sun or of proto-planets in the midplane, the removal of the angular momentum of the collapsing cloud by meridional circulation currents, central heating and the radial temperature gradient. The presence or absence of a central object prior to the formation of proto-planets raises questions concerning the influence of solar wind during the solar flare-up phase and the presence of strong tidal effects. A variety of assumptions concerning these phenomena led to a variety of theories of the early stages of the development of the solar system, and as yet no unique rigorous answer is available. In his theory of the origin of the giant planets, Cameron assumed that in the midplane of the rotating nebula, the temperature had a relatively low value so that the nebula consisted not only of gases but also of dust. The latter was made of metals, metal oxides, sulfides, silicates and perhaps ice; the former of volatile elements and compounds such as hydrogen, helium, methane, ammonia and water. Through accretion and amalgamation, these several-micron-size grains grew to larger particles (1-10mm) and eventually formed a midplane layer of small solids that became gravitationally unstable and formed more massive bodies. Through collision the largest of these bodies grew sufficiently to form planetary cores which could attract their own gaseous clouds co-rotating with them. A hydrodynamic collapse of the clouds released then a large amount of heat which dissociated and ionized $H_2$ and partially ionized $He$.

In the course of time these proto-planets, especially the outer ones, acquired atmospheres made primarily of hydrogen and helium with any in-falling dust probably evaporating. The subsequent development of such planets was accompanied by a slow evolution of heat due to gravitational shrinkage and by progressive cooling. The essential feature of this model is that, while the rocky cores themselves incorporate the various nebular compounds in solar proportions and the external mantles also retain the characteristic solar ratio of hydrogen to helium ($3.5 \pm 1$ by mass), there is no fixed relation between the two so that the planets as a whole are not solar. In particular, there is a large excess of water in the form of ice or vapor.

A different model of the formation of planets has been applied to Jupiter by Bodenheimer. He assumed that the planet was formed by a local selfgravitational condensation of the nebular matter of initial density $10^{-11} g \text{ cm}^{-3}$ at $T=40 K$ in a volume with $r=4600 R_J$. If the sun was already present then the initial density has to be about 500 times higher to overcome disruptive tidal effects. The subsequent evolutionary contraction first proceeded rapidly in quasi-hydrostatic equilibrium until the hydrodynamic collapse associated with the dissociation of $H_2$ had occurred and a denser central region had formed. This was followed by a further slow contraction, in hydrostatic equilibrium, from a radius of about $5R_J$ until the present state was reached. Throughout this process the composition was solar and homogeneous (Fig. 1).