THE INTERIORS OF THE GIANT PLANETS - 1983*

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Abstract. The last few years brought progress in our understanding of the interiors of the giant planets especially of the two larger ones which have been visited by Pioneer and Voyager spacecraft. An analysis of the formation of the giant planets also helped to clarify certain important common features. The presently available model of Jupiter is still based on certain somewhat bothersome approximations but it appears to satisfy the main observational constraints. Saturn’s interior is much better understood than it was previously although the quantitative aspects of the role of the miscibility gap in the hydrogen–helium system have not yet been entirely resolved. Much attention has been directed at the interiors of Uranus and Neptune and the outstanding question appears to be the location and the amount of ices and methane present in their outer layers. Both the two- and the three-layer models are moderately successful. Serious difficulties arise from the considerable uncertainties concerning the rotational periods of both planets. Also the estimates of the internal heat fluxes and of the magnetic fields of both planets are not sufficiently certain. It is hoped that the forthcoming flyby of these two planets by a Voyager spacecraft will provide important new data for a future study of their interiors.

1. Introduction

Improvements in the theory of the interiors of the giant planets are closely related to the availability of new and better observational data of terrestrial or spacecraft origin, of new laboratory results concerning the equations of state and phase diagrams of pertinent elements and compounds at suitably high pressures and temperatures and, last but not least, to the theoretical developments in unravelling the often exceedingly complicated phenomena of convection or magnetic field generation in planetary interiors. Progress in most of these areas can be reported. The interest in a particular planet is of course closely tied in to the, even preliminary, analysis of the results of spacecraft missions to that planet. At present the basic conclusions of the highly successful Pioneer and Voyager missions to Jupiter and Saturn have already been put to good use and the attention of the theorists appears to be shifting to Uranus and Neptune but in the absence of spacecraft data the results are still rather speculative.

Before describing present models of the interiors of the giant planets it should be pointed out that on the basis of a classical accretion mechanism Mizuno (1980) has shown that the mass of the cores of all the giant planets should be about 10 Earth masses $M_E$. In his theory the cores with a mean density of 5.5 g cm$^{-3}$ contain metals, rocks and ices while the envelopes are made of hydrogen and helium treated as ideal gases. Mizuno’s result follows from the assumption that the envelope is in hydrostatic equilibrium, the accretion rate is constant and equals $10M_E$ per $10^7$ years, the luminosity is

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uniform throughout the envelope and is fueled by the gravitational energy released during accretion of planetisimals. The grain opacity in the envelope is about 1 cm² g⁻¹ and the depletion of grains as a function of temperature due to evaporation is taken into account. Figures 1 and 2 show the relation between the core mass $M_c$ and the total mass $M_t$ of a planet forming in the regions of Jupiter and Neptune for various grain depletions $f$. The similarity of the two sets of curves is striking. The critical mass of the core $M_c^*$ for which the gaseous envelope becomes unstable and collapses onto the core depends on the grain depletion factor $f$ as shown in Figure 3. Lewis and Prinn (1970, 1980) pointed out that there are questions about the equilibrium concentration and the molecular form of other