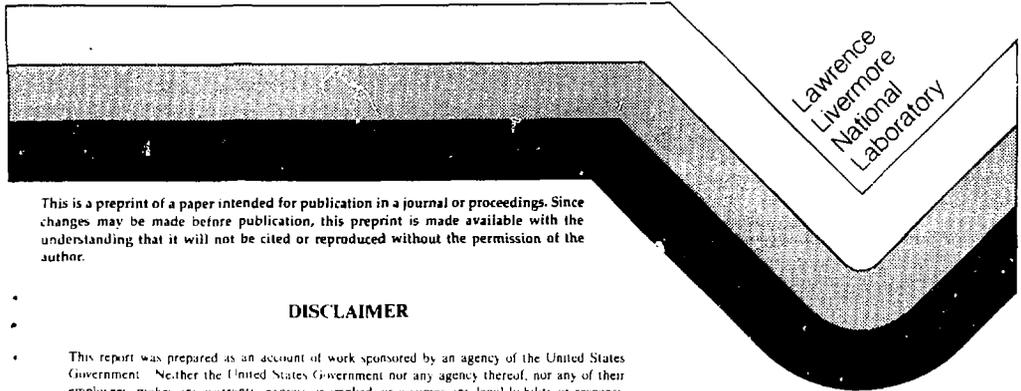# HIGH PRESSURE STUDIES OF PLANETARY MATTER

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DISCLAIMER

HIGH PRESSURE STUDIES OF PLANETARY MATTER

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Those materials which are of greatest interest to the physics of the deep
planetary interiors are Fe, H_2, He and the Ices. These are sufficiently
diverse and intensively studied to offer an overview of present day high
pressure research.

KEY WORDS: Planets, Iron, Hydrogen, Helium, Ices.

INTRODUCTION
For the purpose of discussion the planets may be categorized into two
groups: The terrestrial planets, Earth, Mars, Mercury and Venus which are
made up of the rocky and solid-like material (Fe, metal oxides, silicates
etc.) and the Jovian planets, Jupiter, Saturn, Uranus and Neptune,
consisting of an inner rock core estimated to be about fifteen to twenty
earth masses surrounded by a large volume of dense fluid. Jupiter and
Saturn are made mainly of a solar mixture of H_2 and He (7 parts H_2 to 1
part He by number). Uranus and Neptune which are smaller and are at
lower temperatures have retained considerable amounts of Ice in addition
to their primordial H_2 and He. "Ice," is a term used to denote a planetary
mixture of H_2O, NH_3 and CH_4. Pluto is believed to be mainly made of
Ice. A useful survey on the subject of planetary interiors is the book by
Hubbard (1984).

PHASE DIAGRAM OF IRON
The melting pressure and temperature for iron are of great importance for
constraining the temperature at the center of the earth and has been the
stimulus for several recent and important advances in static and
shockwave methods. Noteworthy are the sound velocity shock melting
measurements of Brown and McQueen (1986), the attempts by Williams
et al., (1987), and of Boehler (1986), to determine the melting curve by
laser heating an iron sample in a diamond-anvil cell and the shock
temperature measurements of Bass (1987).

Boehler reported diamond anvil measurements of the ε-γ (hcp-fcc)
and melting curves to 40 GPa. Figure 1 shows the phase diagram of iron,
combining the results of Boehler with the sound velocity measurements of
Brown and McQueen. Boehler predicted that the γ phase ends in a triple
point near 75 GPa, and he speculated that the shock anomaly at 200 GPa
must correspond to a new high pressure solid phase.

Theoretical calculations (Ross et al., 1989), using the Young and
Grover (1983) model for iron, predict that this anomaly may be caused by
a new high temperature bcc phase, referred to here as α'. This model
predicts that the cp-bcc (ε-α') phase boundary shown in Figure 1 has

a positive dT/dP slope. The theoretical shock Hugoniot crosses the theoretical cp–bcc phase boundary at 130 GPa and 2400 K. Although this differs from the 200 GPa experimental shock anomaly, all considered the agreement is good. If one assumes the calculated cp–bcc phase boundary slope is correct and shifts the boundary to intersect the shock anomaly at 200 GPa, then the first appearance of the new bcc phase is predicted to occur on the melting curve at 150 GPa and 4000 K.
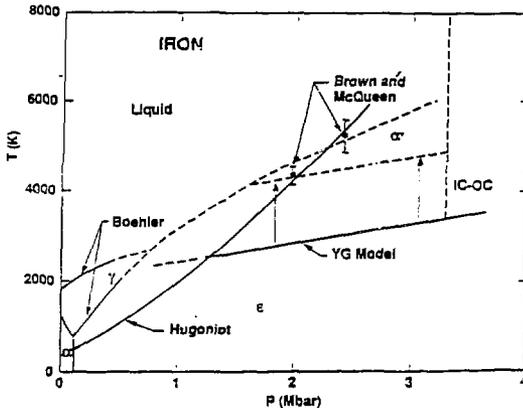

Figure 1. Phase diagram of iron up to Earth core conditions. The experimental phase boundaries of Boehler are shown to 400 kbar and are extrapolated to a ε–γ–liquid triple point. The melting curve is then smoothly drawn through the Brown–McQueen shock anomaly at 2.43 Mbar. The theoretical cp–bcc (ε–α') phase boundary from the YG model is shown, and the arrows indicate a uniform shift necessary to have this boundary intersect the 2.0 Mbar shock anomaly. IC–OC dashed line indicates pressure at inner– outer–core boundary.

THE JOVIAN PLANETS

The low mean densities of Jupiter and Saturn lead us to believe they consist mostly of hydrogen and helium near solar composition. Using equations of state based on shock–wave experiments for H_2 (Ross et al., 1983) and He (Ross and Young, 1986), with an inner rock core, the internal structure of Jupiter can be modeled to explain all of its observed properties, while assuming solar composition of constituent elements (Grossman et al., 1980). Saturn remains anomalous. Calculations show this body has a cooling time that is too long (it is emitting more energy than can be accounted for by contraction) and which may be the result of energy released by the gravitational differentiation of phase separated hydrogen and helium (Stevenson, 1975).

HIGH PRESSURE STUDIES OF PLANETARY MATTER

The simplest models of Uranus and Neptune postulate three layers in which the innermost layer consists of a rock–core of FeO and the outer is mainly H_2 and He. The middle layer is presumed rich in the intermediate mass elements present in accordance with their cosmochemical ratios, O:C:N(7:4:1), and in the form of their hydrides H_2O, CH_4 and NH_3.

The middle layer of Uranus, and Neptune, are of particular interest because a part of their P–T range is attainable by current experimental techniques. The pressures and temperatures calculated for this layer range from about 20 GPa and 200 K at the outer layer boundary, to about 600 GPa and 6000 K at the ice/rock core boundary (Hubbard, 1984). Existing shock–wave data up to nearly 1 Mbar indicates that above this pressure the molecules believed to constitute the ice layer of Uranus and Neptune are highly ionized, and almost completely dissociated. This means that the middle layer is divided into an ionized molecular outer–part and an inner–part at higher temperature and higher pressure which is dissociated and becomes progressively metallic at higher densities.

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