

FEATURES OF HYPOTHETICAL PLASMA PHASE TRANSITION IN THE INTERIOIRS OF SATURN AND JUPITER

Iosilevskiy I.L., Ukrainets A.V.

Moscow Institute of Physics and Technology (State University), Moscow
ilios@orc.ru

Here we consider physics of the matter phase transitions under extreme conditions, which correspond to such astrophysical objects as giant planets, brown dwarfs and some other substellar objects. We examine the anomalous features of one of the hypothetical Plasma Phase Transitions (PPT) [1] – namely the Saumon-Chabrier PPT [2], which is expected to occur in the hydrogen-helium plasma in the interior of Jupiter and Saturn [3]. A number of available theories [3] at constructing equation of state of the hydrogen-helium mixture use the so-called “additivity rule”, when specific volume and specific enthalpy of the mixture at given pressure (P) and (T) temperature are derived as a sum of specific volumes and enthalpies of the components at the same P and T . It has been noted previously [4] that if we consider the final phase diagram of the mixture in (P – T) coordinates the “additivity rule” is equivalent to the transfer of the PPT boundaries of each component onto the summary P – T diagram of the mixture. Thus in P – T representation the structure of the PPT boundaries sums remaining permanent at switching from purely hydrogen [5] or purely helium [6] [7] plasma to the hydrogen-helium mixture [2]. Having investigated the non-congruent nature of the phase equilibrium in the high-temperature mixtures of two and more elements, we expect to find a fundamentally different character of the phase boundaries in the hydrogen-helium plasma of the astrophysical objects.

In this work using tabular data [2] we reconstructed some thermodynamic quantities of the hydrogen-helium plasma in the range of parameters corresponding to the conditions at the co-existence boundaries of the PPT. Using general thermodynamic relations we also reconstructed the characteristics of the coulomb and density corrections (the so-called non-ideality corrections). That allowed us to calculate two previously unknown characteristics of the studied PPT: – (A) the jump of the electrostatic potential, which is generally inherent in any phase transition in equilibrium Coulomb systems [8], at the phase boundary of the PPT [2], and (B) typical scale of the PPT non-congruency value (the differences in stoichiometry of the co-existing phases). While the first effect – the potential of the phase boundary – turned out to be within the typical scale of the contact electrochemical quantities [8], $\Delta\phi \sim 1\text{-}2$ eV (Fig.1), the second quantity – the PPT non-congruency – is rather considerable under conditions inside Saturn and Jupiter. the value and (which is much more important) the sign of the non-congruency are in good agreement with the experimentally observed helium deficiency in the atmosphere of the giant planets [9] (see Fig. 2). According to the review [9] $Y(\text{He})_{\text{Jupiter}} \approx 0.231$ and $Y(\text{He})_{\text{Saturn}} \approx 0.215$. It should be noted that one of the aims of the Cassini-Huygens apparatus, which is now on the orbit of Saturn, is to check and to derive more accurately the above mentioned helium abundance in the Saturn atmosphere.

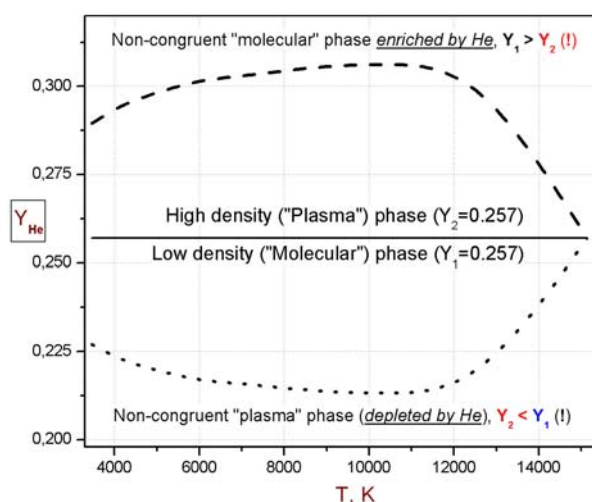
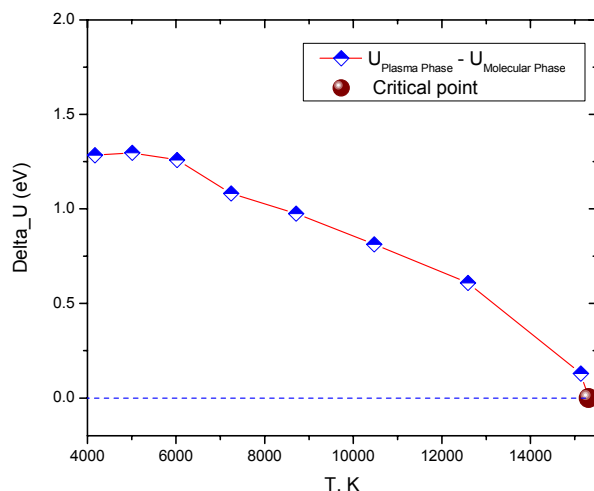


Fig. 1. Potential of the phase boundary of the hypothetical plasma phase transition (PPT) (in version of Saumon & Chabrier [2]).

Fig. 2. The non-congruence of the hypothetical PPT in the hydrogen-helium mixture in the interior of Jupiter and Saturn ($Y_{\text{He}} \sim 0.257$). Dependence of helium abundance on temperature for coexistent “plasma” and “molecular” phases.

The next step of the investigation is to reconstruct the value of the splitting of the boiling curve $P_{\text{boil}}(T)$ and the saturation curve $P_{\text{sat}}(T)$ on one P - T diagram, which is typical of the non-congruent phase transitions [4]. Another way to continue the study is to conduct the same reconstruction procedure of the electrostatics and the non-congruency in some other of numerous versions of PPT in hydrogen-helium mixture described in the literature (see [10]), including the PPT, which originates in the computations conducted using the “chemical plasma model” implemented in SAHA-IV [11] [12] at a definite combination of the interaction parameters of the particles composing the Hydrogen-Helium mixture.

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