

# Molecular Hydrogen in the Ionized Region of Planetary Nebulae

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**Abstract.** This work presents an analysis of the concentration of the hydrogen molecule inside the ionized region of planetary nebulae (Aleman & Gruenwald 2004). Models for typical PNe are obtained with the photoionization code AANGABA (Gruenwald & Viegas 1992). The equations corresponding to the ionization and chemical equilibria of H, H<sup>+</sup>, H<sup>-</sup>, H<sub>2</sub>, H<sub>2</sub><sup>+</sup>, and H<sub>3</sub><sup>+</sup> are coupled with the equations of ionization and thermal balance for a photoionized atomic gas. A total of 40 different reactions related to the formation or destruction of these species are included. The presence of dust is taken into account, since grains act as catalysts for the production of H<sub>2</sub> as well as shield the molecules against the stellar ionizing radiation.

The effect of the stellar temperature ( $T_*$ ) and luminosity ( $L_*$ ) as well as that of the gas density ( $n_H$ ), dust-to-gas mass fraction, and grain material on the obtained abundance of the hydrogen molecule is analyzed. It is shown that a significant concentration of H<sub>2</sub> can survive inside the ionized region of planetary nebulae, mostly in the inner region of the recombination zone, where the ionization degree is of the order of 0.1. We conclude also that the H<sub>2</sub> to total hydrogen nuclei mass ratio ( $R_M$ ) increases with the relative thickness of the recombination zone. This explains why  $R_M$  increases with  $T_*$  and decreases with  $n_H$  and  $L_*$ , the main effect being due to the stellar temperature. This is an interesting result, since hotter stars produce more high-energy photons. However, since the hydrogen photoionization cross section decreases with the photon energy, high-energy photons can travel farther into the nebula before being absorbed by the gas, producing a more extended recombination zone. Plots of  $R_M$  versus  $T_*$  are shown in Figure 1, for different values of  $L_*$ . Our results can explain why the H<sub>2</sub> emission is more frequently observed in bipolar planetary nebulae (Gatley's rule), since this kind of object typically has hotter stars.

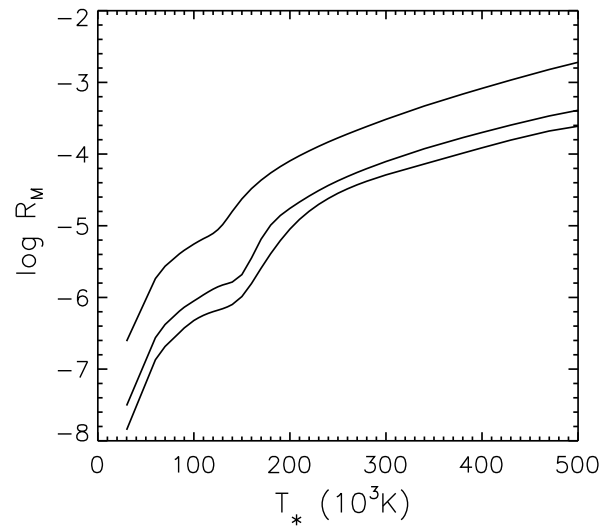
Molecular and atomic hydrogen masses for the Ring Nebula (NGC 6720) were derived from observations by Greenhouse et al. 1988, resulting in a molecular to atomic gas ratio equal to  $\sim 7 \times 10^{-5}$ . Assuming the equilibrium between formation on grain surface and photodissociation, these authors conclude that chemical equilibrium does not account for the detected quantity of H<sub>2</sub>. However, from our more detailed model and assuming the parameters for the central star and the gas given by Greenhouse et al. 1988, we obtain  $R_M = 2.4 \times 10^{-5}$ , which is reasonably similar to the value obtained by these authors. Financial support: CAPES/PROEX.

**Keywords.** ISM: molecules, planetary nebulae: general, molecular processes, astrochemistry

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## References

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**Figure 1.** Molecular hydrogen mass fraction versus central stellar temperature. The results are shown for  $L_* = 500, 3000,$  and  $10^4 L_{SUN}$ , with  $R_M$  decreasing with increasing  $L_*$ .