July 10, 2018

PROBLEMS　Astrophysics II　(Satoshi Yamamoto)

Important Notes

1. Solve the following three problems. Prepare your report using A4 sheets, and put your name, course, and student ID on the top page.
2. Submit your report to the administration office (Kyomu) of the physics department.
3. The deadline is 17:00 (JST) on July 31, 2018 (Tue).
4. Submission by e-mail or fax is NOT accepted.

Problem 1: Estimate a typical ionization degree each for a diffuse cloud and a molecular cloud with a brief justification. Here, we assume that the H_2 density of a diffuse cloud is 100 cm^{-3} and that of a molecular cloud is 10^4 cm^{-3}. Here, the hydrogen is assumed to be in a molecular form. Furthermore, the cosmic ionization rate of H_2 of 1×10^{-17} s^{-1}, the rate coefficient of electron recombination reactions of 1×10^{-7} cm^3s^{-1}, and the elemental abundance of carbon relative to H_2 of 10^{-4} should be used.

Problem 2: In general, the time scale for the chemical equilibrium is give as:

$$\frac{1}{\tau} = \frac{1}{t_f} + \frac{1}{t_d},$$

where t_f and t_d represents formation and destruction timescales of molecules, respectively. Estimate the time scale for the chemical equilibrium for a diffuse cloud, and compare it with the free fall time of a cloud with the H_2 density of 100 cm^{-3}. Assume that the photodissociation rate is typically 10^{-10} s^{-1}.

Problem 3: In a molecular cloud, deuterium mainly exists in the form of HD, and its abundance relative to H_2 is 10^{-5}. It is well known that the D/H ratio of molecules other than H_2 tends to be much higher than 10^{-5}. This phenomenon is called as 'deuterium fractionation'. It is triggered by the following reaction:

$$H_3^+ + HD \rightarrow H_2D^+ + H_2$$

This is exothermic by 230 K, and hence, the backward reaction can be ignored at the low-temperature condition (10 K) of a molecular cloud, as far as para H_2 is considered. For this reason, deuterium is fractionated in the H_3^+ ion. The H_2D^+ thus formed is broken up by the ion-molecule reaction with CO and the electron recombination reaction. Considering these reactions, set up the rate equation for H_2D^+, and evaluate the ratio of $[H_2D^+]/[H_3^+]$ under the steady-state approximation for the two cases of the CO abundances relative to H_2: 10^{-4} (no depletion of CO onto dust grains) and 0 (complete depletion). Here, assume the H_2 density and the temperature to be 10^4 cm^{-3} and 10 K, respectively. Use the ionization degree obtained in Problem 1 for this problem. Also assume the rate coefficients of the electron recombination reaction and the ion-molecule reaction to be 1×10^{-7} cm^3s^{-1} and 1×10^{-9} cm^3s^{-1}, respectively.