Assignment #8: due July 3

1. **H_2 formation in the ISM**

   (a) Explain why the direct radiative association reaction

   $$H + H \rightarrow H_2 + \gamma, \tag{1}$$

   is not an important source of H_2 in the ISM. [**Note**: γ indicates the emission of a photon].

   (b) H_2 can form in the gas phase via the reaction chain

   $$\begin{aligned} H + e^- &\rightarrow H^- + \gamma, & (2)\\ H^- + H &\rightarrow H_2 + e^-. & (3) \end{aligned}$$

   However, some of the H^- ions formed by reaction 3 are destroyed by mutual neutralization with H^+:

   $$H^- + H^+ \rightarrow H + H. \tag{4}$$

   Write down an expression for the formation rate of H_2 as a function of the rate coefficients of the three reactions (k_2, k_3, k_4) and the number densities of electrons and atomic hydrogen. [**Note**: assume that the cloud consists of pure hydrogen].

   (c) Consider a cold neutral cloud with $n_H = 100\,\mathrm{cm}^{-3}$, $n_{H^+} = 1\,\mathrm{cm}^{-3}$, and $T = 100$ K that initially contains no molecules. Estimate the time required to convert half of the hydrogen into molecular form. Assume that n_{H^+} does not vary, and use the following values for the rate coefficients of the reactions discussed in part (b):

   $$\begin{aligned} k_2 &= 10^{-18} T\,\mathrm{cm}^3\,\mathrm{s}^{-1}, & (5)\\ k_3 &= 1.2 \times 10^{-9}\,\mathrm{cm}^3\,\mathrm{s}^{-1}, & (6)\\ k_4 &= 2.4 \times 10^{-6} T^{-1/2}\,\mathrm{cm}^3\,\mathrm{s}^{-1}. & (7) \end{aligned}$$

   (d) Compare your answer to part (c) with the recombination time of the gas:

   $$t_{\mathrm{rec}} = \frac{1}{\alpha n_{H^+}}, \tag{8}$$

   where $\alpha = 1.88 \times 10^{-10} T^{-0.64}\,\mathrm{cm}^3\,\mathrm{s}^{-1}$. Estimate how much H_2 will form within one recombination time. What does you result imply regarding the ability of reactions 2 & 3 to produce a large amount of H_2 in the ISM?