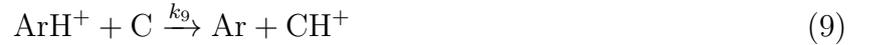


Exercise: ArH⁺ Chemical Network

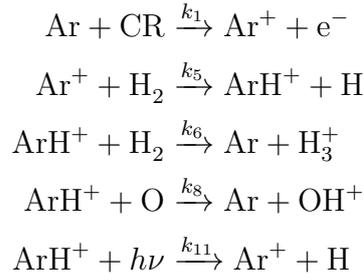
ArH⁺ (argonium), the first noble gas molecule to be detected in space (Barlow et al. 2013, *Science*, 342, 1343), is considered a very good tracer of the atomic gas in the ISM (Schilke et al. 2014, *A&A*, in press). The following is a simple reaction scheme describing the formation and destruction pathways of ArH⁺.



1. Classify each type of reaction in the chemical network
2. Write the ordinary differential equation (ODE) which describes the rate of change of abundance of ArH⁺ as a function of time
3. Assuming steady state for all species, i.e., $dn/dt = 0$, derive the following expression (Schilke et al. 2014, *A&A*, in press) for the abundance ratio of ArH⁺ and Ar in the diffuse ISM,

$$\frac{n(\text{ArH}^+)}{n(\text{Ar})} = \frac{\zeta(\text{Ar})}{k_6 n(\text{H}_2) + k_8 n(\text{O})} \quad , \quad (12)$$

where $\zeta(\text{Ar}) = k_1$ is the cosmic-ray ionization rate of Ar. According to Schilke et al. 2014, the following reactions *only* contribute significantly to the formation and destruction of ArH⁺,



Tip: you need the expressions describing the steady-state abundances of both ArH^+ and Ar^+ .

4. Consider now the following values for a diffuse molecular cloud:

$$\begin{aligned}
k_1 &= 11.4 \zeta_p(\text{H}) \text{ s}^{-1} \\
k_6 &= 8.0 \times 10^{-10} \text{ cm}^3 \text{ s}^{-1} \\
k_8 &= 8.0 \times 10^{-10} \text{ cm}^3 \text{ s}^{-1} \\
\zeta_p(\text{H}) &= 2.0 \times 10^{-16} \text{ s}^{-1} \\
n(\text{O}) &= 2.9 \times 10^{-4} n_{\text{H}} \\
n(\text{Ar}) &= 3.2 \times 10^{-6} n_{\text{H}}
\end{aligned}$$

(a) How does the ArH^+ abundance change as a function of the logarithmic molecular fraction $\log_{10}(2n(\text{H}_2)/n_{\text{H}})$? Evaluate the expression for these values:

$$\begin{aligned}
\log_{10}(2n(\text{H}_2)/n_{\text{H}}) &= -1.0 \\
\log_{10}(2n(\text{H}_2)/n_{\text{H}}) &= -2.5 \\
\log_{10}(2n(\text{H}_2)/n_{\text{H}}) &= -3.5 \\
\log_{10}(2n(\text{H}_2)/n_{\text{H}}) &= -4.0
\end{aligned}$$

(b) How can we conclude from this that ArH^+ is a good atomic gas tracer?