Exercise 5: Simplified ionosphere chemistry (derived from [Schunk, 1988])

Chemistry

$$O^+ + N_2 \xrightarrow{k_1} NO^+ + N$$
$$O^+ + O_2 \xrightarrow{k_2} O + {O_2}^+$$
$${O_2}^+ + e \xrightarrow{k_3} 2\,O$$
$${N_2}^+ + O \xrightarrow{k_4} O^+ + N_2$$
$${N_2}^+ + O_2 \xrightarrow{k_5} {O_2}^+ + N_2$$
$${O_2}^+ + N \xrightarrow{k_6} NO^+ + O$$
$$NO^+ + e \xrightarrow{k_7} N + O$$

Ionization

$$O \underset{k_8}{\overset{k_9}{\rightleftharpoons}} O^+ + e$$
$$O_2 \underset{k_{10}}{\overset{k_{11}}{\rightleftharpoons}} {O_2}^+ + e$$
$$N_2 \underset{k_{12}}{\overset{k_{13}}{\rightleftharpoons}} {N_2}^+ + e$$

Question

Complete the provided template. Simulate the system at the provided conditions. For simulation, use `scipy.integrate.solve_ivp` and specify `'LSODA'` as method high-performance method.

Rate coefficients

$$k_1(T) = 1.533 \times 10^{-12} - 5.92 \times 10^{-13} \frac{T}{300\,\mathrm{K}} + 8.6 \times 10^{-14} \left(\frac{T}{300\,\mathrm{K}}\right)^2$$
$$k_2(T) = 2.82 \times 10^{-11}$$
$$k_3(T) = 1.6 \times 10^{-7} \left(\frac{300\,\mathrm{K}}{T}\right)^{0.55}$$
$$k_4(T) = 1 \times 10^{-11} \left(\frac{300\,\mathrm{K}}{T}\right)^{0.23}$$
$$k_5(T) = 5 \times 10^{-11} \frac{300\,\mathrm{K}}{T}$$
$$k_6(T) = 1.2 \times 10^{-10}$$
$$k_7(T) = 1 \times 10^{-11} \left(\frac{300\,\mathrm{K}}{T}\right)^{0.85}$$
$$k_8(T) = k_{10} = k_{12} = 1 \times 10^{-8}$$
$$k_9(T) = k_{11} = k_{13} = 1 \times 10^{-5}$$