We often apply optical emission spectroscopy (OES) measurement to examine plasmas. Line intensities of the plasmas indicate number densities of upper states of the transition $N_p$ ($p = 1, 2, \ldots, M$ in the ascending order of energy; $p = 0$ as a ground state), which are theoretically described by collisional-radiative (CR) model as functions of electron temperature $T_e$ and density $N_e$. From the mathematical point of view, the governing equations of the CR model are categorized as first-order nonhomogeneous linear ordinary differential equations (ODE) with constant coefficients, where unknown functions are number densities of excited states $N_p$: \begin{equation}
\frac{dN}{dt} = aN + \delta, \tag{1}
\end{equation}
where bold fonts denote vectors,
\begin{equation}
N = \begin{pmatrix} N_1 \\ N_2 \\ \vdots \\ N_M \end{pmatrix}, \quad \delta = \begin{pmatrix} \delta_1 \\ \delta_2 \\ \vdots \\ \delta_M \end{pmatrix},
\end{equation}
\begin{equation}
a_{ij} = \begin{cases} 
N_e C_{ji} & \text{for } j < i, \\
N_e C_{ji} + A_{ji} & \text{for } j > i, \\
-N_e \left( S_i + \sum_{l=0,\neq i}^{M} C_{il} \right) & \text{for } j = i,
\end{cases} \tag{3}
\end{equation}
\begin{equation}
\delta_i = \alpha_i N_e^3 + \beta_i N_e^2 + C_{0i} N_e N_0. \tag{4}
\end{equation}
Symbols used above are as conventions in this field [1]. The solution to Eq. (1) is given by the sum of the general solution of the associate homogeneous ODE and anyone of the particular solutions to the non-homogeneous equation, Eq. (1), one of which is the steady-state solution, \begin{equation}
N = -a^{-1}\delta = -a^{-1}\delta_{\text{sec}} - a^{-1}\delta_{\text{ion}} = -\left(\alpha N_e^3 + \beta N_e^2\right) - C_{0i} N_e N_0, \tag{5}
\end{equation}
on which almost all the discussions have been concentrated up to now. If we treat transient response, however, we must discuss time-dependent solutions and examine eigenvalues. The general solutions to the associate homogeneous ODE is given as \begin{equation}
N(t) = \sum_{i=0}^{M} C_i \exp(\lambda_i t) \xi_i, \tag{6}
\end{equation}where $\xi_i$ is the eigenvector corresponding to the eigenvalue $\lambda_i$ and $C_i$ are arbitrary constants. We can prove that the real part of any eigenvalue is negative by Gershgorin’s theorem [2]. Figure 1 shows the dependence of the real part of inverse relaxation time $\lambda_1$ of Ar plasma [1]. It is found that $|\text{Re}(\lambda_1)|$ is approximately proportional to the electron density $N_e$. Since it is found that $|\text{Re}(\lambda_1)|^{-1}$ becomes several tens of microsecond for $N_e \sim 10^{11}$ cm$^{-3}$, we should be very careful about the treatment of the excited states as steady-state. [1] H. Akatsuka, Phys. Plasmas 16 043502 (2009). [2] H. Akatsuka, The Papers Tech. Meeting on Plasma Sci. Technol. IEEJ, PST-10-80/PPT-10-124, pp. 67 - 72 (2010).