Chlorine discharges diluted with argon:

The dissociation and the electronegativity

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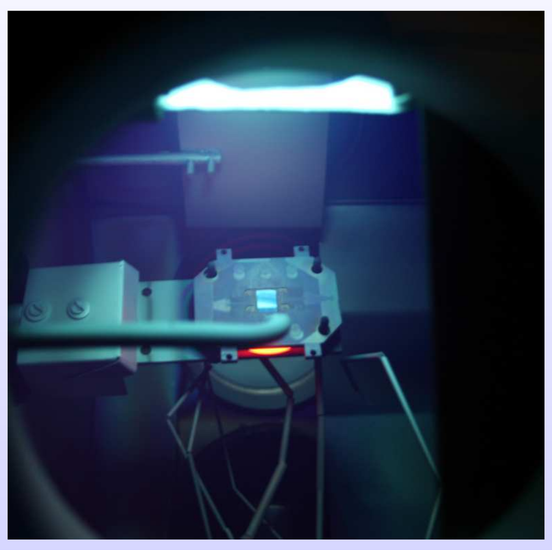

Introduction

- A global (volume averaged) model is applied to study a low pressure (1 – 100 mTorr) high density Cl_2/Ar discharge in the steady state.
- Based on previous models of O_2/Ar (Gudmundsson and Thorsteinsson, 2007), nitrogen (Thorsteinsson and Gudmundsson, 2009b) and chlorine (Thorsteinsson and Gudmundsson, 2009a) discharges.

The global (volume averaged) model

- In addition to electrons, the discharge consists of ground state chlorine molecules $Cl_2(X\,^1\Sigma_g^+, v = 0)$, vibrationally excited chlorine molecules $Cl_2(X\,^1\Sigma_g^+, v = 1-3)$, ground state chlorine atoms $Cl(3p^5\,^2P)$, negative chlorine ions Cl^-, positive chlorine ions Cl^+ and Cl_2^+, ground state argon $Ar(3s^23p^6)$, metastable argon Ar^m ($1s_5$ and $1s_3$), radiatively coupled levels Ar^r ($1s_4$ and $1s_2$) and positive argon ions Ar^+.
- Electrons are assumed to have a Maxwellian-like energy distribution in the range 1 – 7 V.
- The gas temperature is dependent on both power and pressure as in a pure chlorine discharge (Donnelly and Malyshev, 2000).
- The wall recombination coefficient γ_{rec} is dependent on the chlorine dissociation fraction (Stafford et al., 2009).
- The collisional energy loss per electron-ion pair created is defined as

$$\mathcal{E}_c = \mathcal{E}_{iz} + \sum_i \mathcal{E}_{ex,i}\frac{k_{ex,i}}{k_{iz}} + \frac{k_{el}}{k_{iz}}\frac{3m_e}{m_i}T_e \qquad (1)$$

where $\mathcal{E}_{iz}$ is the ionization energy, $\mathcal{E}_{ex,i}$ is the threshold energy and $k_{ex,i}$ is the rate coefficient for the i-th excitation process and k_{iz} is the ionization rate coefficient.

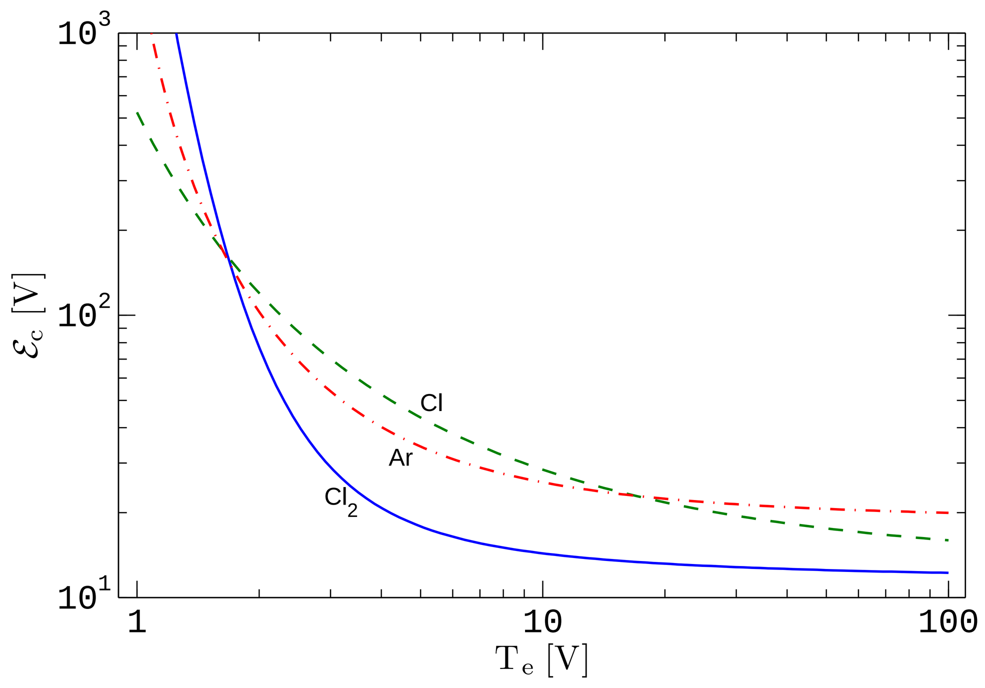

Figure 1: The collisional energy loss per e-Cl_2^+, e-Cl^+ and e-Ar^+ electron-ion pairs created versus the electron temperature.

- At high energy the collisional energy loss is mainly determined by $\mathcal{E}_{iz}$: 11.5 eV for Cl_2, 13.0 eV for Cl and 15.8 eV for Ar.

Results and discussion

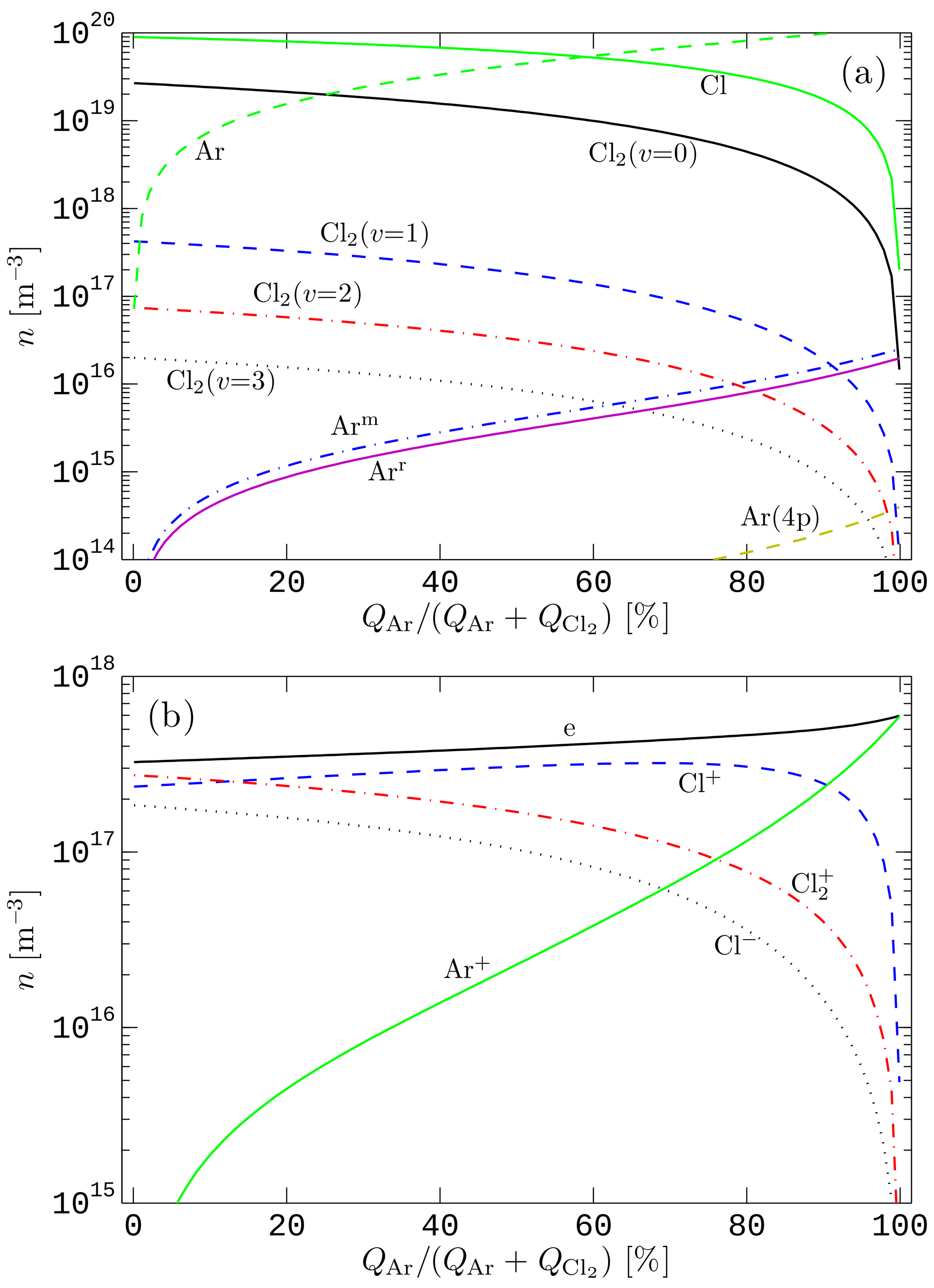

Figure 2: The densities of (a) neutral and (b) charged chlorine and argon particles versus the fractional flow of argon into the chamber.

- The pressure is $p = 10$ mTorr, the power $P_{abs} = 500$ W and the total gas flow rate $Q_{Cl_2} + Q_{Ar} = 100$ sccm.
- The chamber is assumed to be made of stainless steel, cylindrical with the dimensions $R = 10$ cm and $L = 10$ cm.
- The Cl^+ density increases with decreasing chlorine content until the source gas flow is 68 % Ar while other densities decrease.
- The electron temperature, shown in figure 3, increases significantly with argon content at low pressure but decreases at high pressure.
- The chlorine dissociation fraction, shown in figure 4, increases and becomes less dependent on pressure as the argon content is increased.
- The electronegativity, shown in figure 5, decreases similarly with increased argon content at every power and pressure explored.

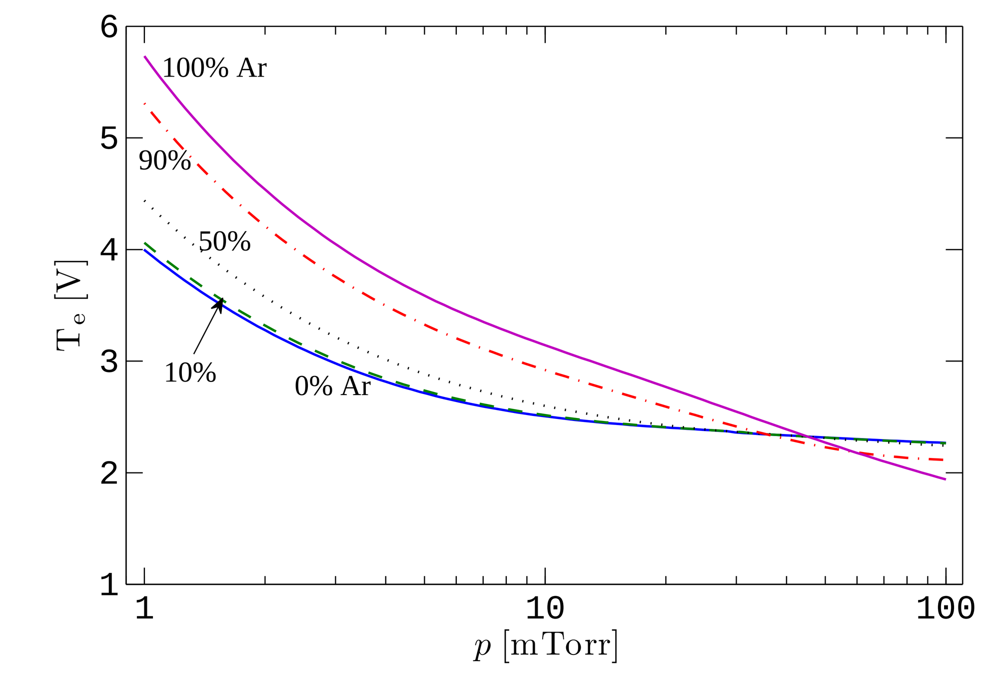

Figure 3: The electron temperature versus pressure for pure chlorine, argon diluted chlorine (10, 50, 90 % Ar) and pure argon gas flows.

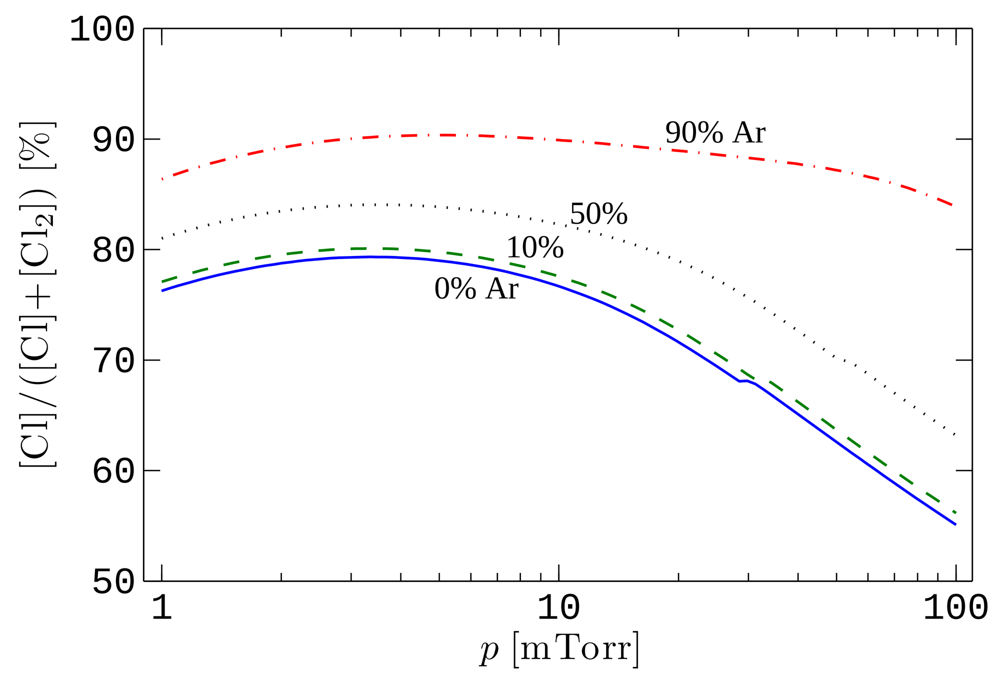

Figure 4: The chlorine dissociation fraction versus pressure for pure and argon diluted (10, 50 and 90 % Ar) chlorine gas flows.

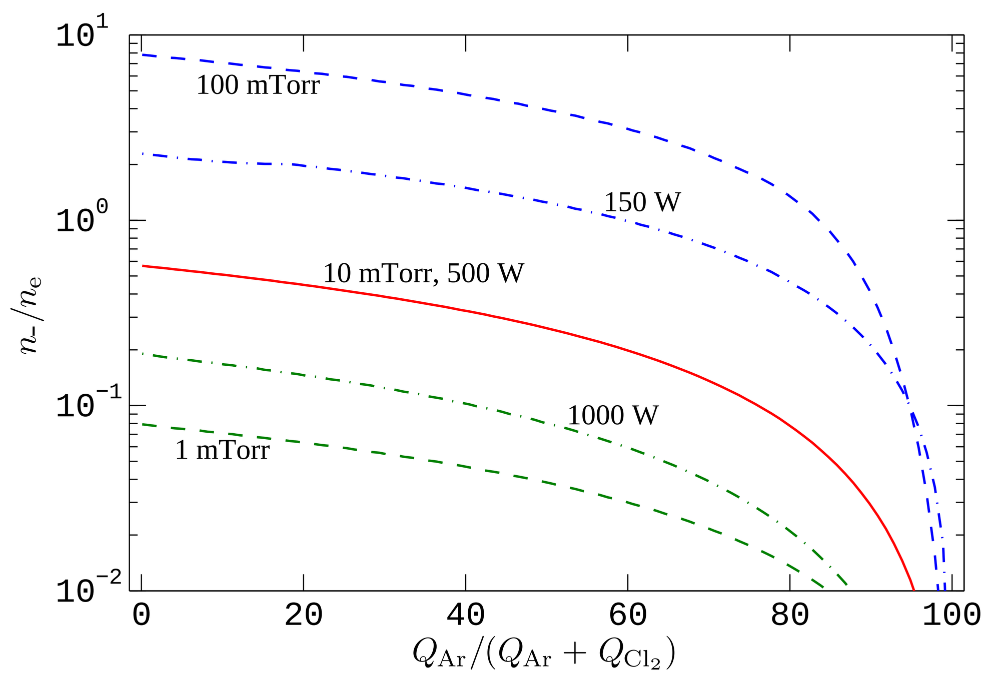

Figure 5: The electronegativity versus argon content for varying pressure ($p = 1$, 10 and 100 mTorr) at $P_{abs} = 500$ W and for varying power ($P_{abs} = 150$, 500, and 1000 W) at $p = 10$ mTorr.

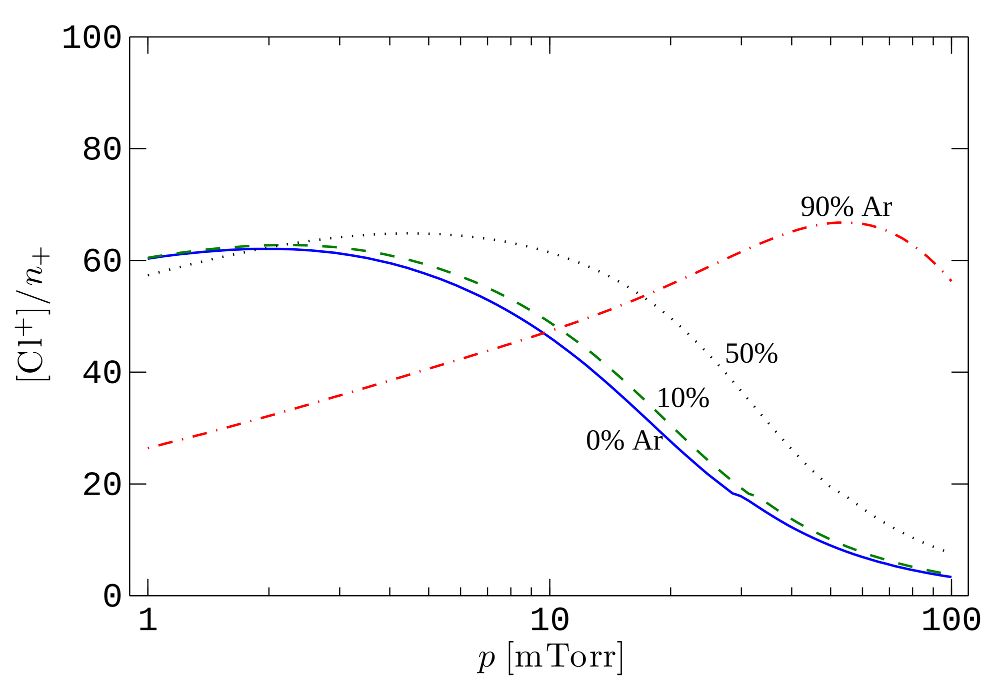

Figure 6: The fraction of Cl^+ of the total positive ion density $n_+ = [Cl^+] + [Cl_2^+] + [Ar^+]$ versus pressure for pure and argon diluted (10, 50 and 90 % Ar) chlorine gas flows.

- The fractional concentration of Cl^+, shown in figure 6, peaks at low pressure in a pure and lightly argon diluted discharge but when the argon content is high it peaks at high pressure.
- The total reaction rate for Cl^+ creation/destruction, shown in figure 7, increases with argon content until 62 % of the gas flow is Ar.
- Although most Cl^+ ions are created by electron impact ionization, the contribution of charge transfer from Ar^+ increases with argon content, being 21 % in an argon dominated discharge.
- The contribution of bulk processes to Cl^+ loss decreases with argon content while wall recombination becomes the only important loss process at high argon content.

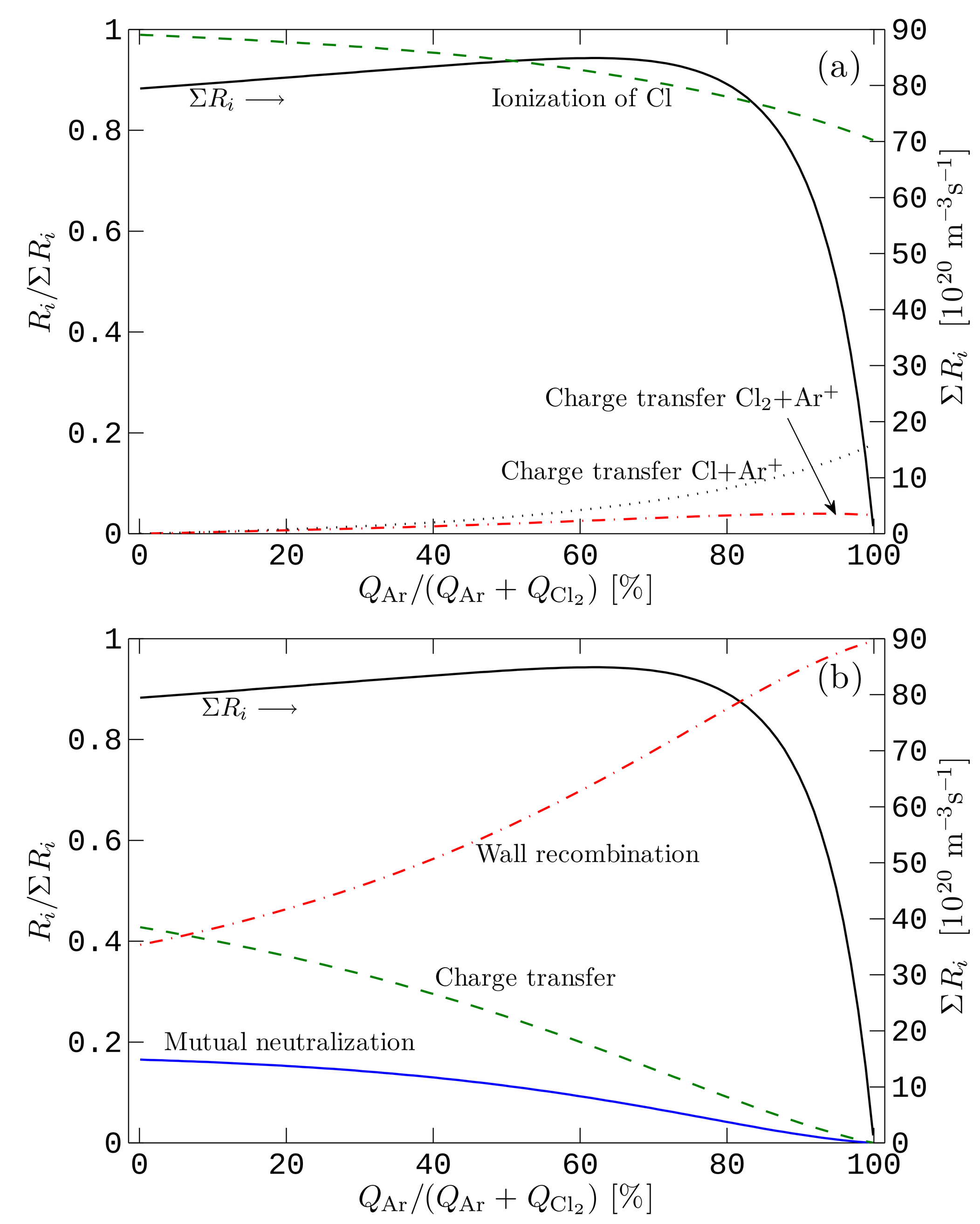

Figure 7: The total and relative reaction rates for (a) the creation and (b) the destruction of Cl^+ ions versus the fractional flow of argon into the chamber.

Conclusions

- The electron temperature increases with argon content as a result of the higher ionization potential of Ar than of Cl or Cl_2.
- The chlorine dissociation fraction increases significantly and becomes less dependent on pressure with increased argon content.
- The electronegativity decreases with argon content for the entire range of pressure and power explored.
- The dependence of the $[Cl^+]/n_+$ fraction on pressure can be changed substantially by diluting the discharge with argon.

Acknowledgments

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