

## EFFICIENT MODELS FOR PHOTOIONIZATION PRODUCED BY STREAMER DISCHARGES IN AIR

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**Abstract.** In this work, we discuss three models to calculate the photoionization produced by non-thermal discharges in air: the classical Zheleznyak integral model and two differential equation based models (three-group SP<sub>3</sub> and three-exponential Helmholtz [1]). The advantage of differential models over the integral model is the simplicity of the implementation of this type of models. We apply these three models to the simulation of the streamer propagation in inhomogeneous electric fields at two different pressures. At atmospheric pressure, the agreement between all three models is excellent. At a reduced pressure (0.05 Torr), the three-group SP<sub>3</sub> model exhibits a notably better performance than the three-exponential Helmholtz model. In addition, the possibility of formulating a consistent set of equations and boundary conditions based on radiative transfer physics is a significant advantage of the SP<sub>3</sub> model in comparison with the Helmholtz model.

### 1. INTRODUCTION

Filamentary streamer discharges exhibit a considerable range of spatial scales, from a few millimeters long microdischarges in dielectric barrier discharges at ground pressure to large-scale electrical discharges present in the mesosphere/lower ionosphere above large thunderstorms, so-called sprites, which can propagate over a few tens of kilometers [2, 3]. Streamers emit radiation in a wide spectral range. The radiation plays an important role in the development of the streamer discharge through two physical processes: photoionization (i.e., ionization of neutral molecules due to the absorption of UV photons emitted from the high-field region of the streamer head) and photoemission (i.e., emission of electrons at electrode surfaces due to absorption of photons). In this work, we focus on the modeling of the photoionization produced by streamers developing in air.

### 2. CLASSICAL INTEGRAL MODEL FOR PHOTOIONIZATION IN AIR

In air, the most widely used model for photoionization is the integral equation based model developed by Zheleznyak *et al.* [4]. In this model, the photoionization source term at position  $\vec{r}$  due to the photon emission at  $\vec{r}'$  is given by

$$S_{ph}(\vec{r}) = \iiint_{V'} \frac{I(\vec{r}')g(R)}{4\pi R^2} dV' \quad (1)$$

where  $R=|\vec{r}-\vec{r}'|$ . In this model, to simplify calculations, the production of photons is assumed to be proportional to the ionization production rate  $S_i$ , and then  $I(\vec{r})$  is given by

$$I(\vec{r}) = \xi \frac{n_u(\vec{r})}{\tau_u} = \frac{p_q}{p+p_q} \xi \frac{\nu_u}{\nu_i} S_i(\vec{r}) \quad (2)$$

where  $\xi$  is the photoionization efficiency,  $n_u(\vec{r})$  is the density of the radiative excited species  $u$ , the ratio  $p_q/(p+p_q)$  is a quenching factor,  $\tau_u$  is the lifetime of the excited state  $u$  accounting for the effects of spontaneous emission and quenching (i.e.,  $\tau_u = p_q/(A_u(p+p_q))$ ), where  $A_u$  is the Einstein