Ambipolar Electric Field and Diffusive Cooling of Electrons in Meteor Trails

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Kelley and Price [GRL, 44, 2987, 2017] recently indicated that ambipolar electric fields may play a role in dynamics of dense plasmas generated by meteors. In the present work we discuss time dynamics of relaxation of electron temperature in meteor trails under relatively common conditions when meteor trail diffusion is not affected by the geomagnetic field (i.e., at low altitudes where both electrons and ions are not magnetized, or at higher altitudes in the plane defined by the trail and magnetic field when meteor trail is not aligned with the geomagnetic field [Ceplecha et al., Space Sci. Rev., 84, 327, 1998, and references therein]). The rate of ambipolar diffusion is a function of temperature and pressure [e.g., Hocking et al., Ann. Geophys., 34, 1119, 2016; Silber et al., Mon. Not. RAS, 469, 1869, 2017] and there is a significant spectroscopic evidence of initial plasma temperatures in meteor trails on the order 4400 deg K [Jennikens et al., Astrobiology, 4, 81, 2004]. For a representative altitude of 105 km chosen for our studies the results are consistent with previous analysis conducted in [Baggeley and Webb, J. Atm. Terr. Phys., 39, 1399, 1977; Ceplecha et al., 1998] indicating that the electron temperature remains elevated for significant time durations measured in tens of milliseconds. Our results indicate that in terms of their magnitudes the ambipolar electric fields can exceed the critical breakdown field of air, consistent with ideas expressed by Kelley and Price [GRL, 44, 2987, 2017], however, under considered conditions these fields lead to acceleration of electron cooling, with electron temperatures falling below the ambient air temperature (below 224 deg K at 105 km altitude). These effects are referred to as diffusive cooling [e.g., Rozhansky and Tsendin, Transport phenomena in partially ionized plasma, Taylor & Francis, 2001, p. 449] and represent a process in which diffusing electrons move against the force acting on them from ambipolar electric field and lose thermal energy. Under considered conditions electron heating in super elastic collisions with rotationally excited ambient molecules becomes important and we will illustrate related time scales by Monte Carlo simulations based on modeling framework of [Frost and Phelps, Phys. Rev., 127, 1621, 1962; Hake and Phelps, Phys. Rev., 158, 70, 1967].