Cross sections and modelling results for TGF- and positron spectrum produced by a negative stepped lightning leader

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We model the energy resolved angular distribution of TGFs and of positrons produced by a negative lightning leader stepping upwards in a thundercloud. First we present our new results for doubly differential cross sections for Bremsstrahlung and pair production based on the triply differential cross-sections of Bethe and Heitler. Other cross sections in literature and databases do not cover the appropriate energy range or do not apply to the small atomic numbers of nitrogen and oxygen or do not resolve both energies and emission angles of emitted photons or positrons. Second we have extended the Monte Carlo model of Chao Li towards relativistic electron energies, and we have included the new cross sections as well as Compton scattering of photons and photo ionization. We will present the angular resolved spectrum of TGFs and positrons of stepped negative leaders and compare it with results of other authors.

1. Cross sections for Bremsstrahlung and pair production relevant for terrestrial thunderstorms

If electrons scatter on the neutrals of the background gas, they can produce hard Bremsstrahlung photons. The Bethe Heitler cross section for Bremsstrahlung [1] is appropriate for a large energy range for the constituents of air as they have nuclei with small atomic number Z. The triply differential cross section of Bethe and Heitler parametrizes all the energies and all the relative angles of incident and scattered electron and of the generated photon. We need to resolve both relative angle and energy of an emitted energetic photon; therefore we have analytically integrated out the angles parametrizing the scattered electron in [2] and derived the required doubly differential cross-section.

This information was previously not available. As we discuss in [2], other literature and databases, e.g. in Geant4, do not deliver the necessary information. Either they do not give the correlation between photon energy and emission angle, or they do not cover the needed energy range or the required range of small atomic numbers.

The Bremsstrahlung photons can interact with the neutrals and ions of the background gas and produce electron positron pairs, if they have sufficient energy. A clear positron signal from thunderstorms was recently seen in [3]. The cross section for pair production in the field of a nucleus shows a quantum-physical symmetry to that of Bremsstrahlung [1]; thus we can use the results for Bremsstrahlung and obtain a correlation between positron energy and its emission angle relative to the direction of Bremsstrahlung photons.

2. Simulation of TGF's and positrons produced by a stepping leader

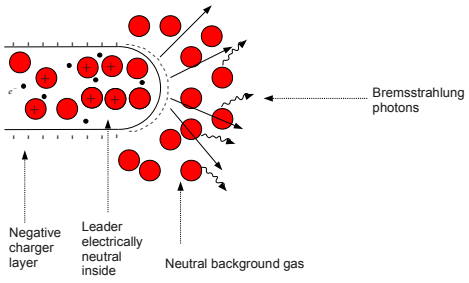

Figure : A negative stepped leader: the ionized interior is charge neutral and consists of neutrals (red circles) and equal amounts of ions (red circles with a "+") and electrons (black points). On the surface there is an electron overshoot that electrically screens the interior and enhances the electric field at the tip. Electrons from this layer are accelerated (solid lines) by this electric field. When they interact with air molecules, they can produce Bremsstrahlung photons.

Above thunderclouds hard X- and gamma-rays (Terrestrial Gamma-ray flashes/TGFs) and positrons are observed [3,4]. Likewise hard X-

rays are observed in laboratory discharges. We model a negative stepped leader moving upwards in a thundercloud, as sketched in figure 1. While the leader steps [5], electrons are accelerated from the surface of the leader by the high field ahead of it. We have simulated these electrons with a Particle-in-Cell Monte Carlo code. We start from the code of Chao Li [6,7] and have extended it with relativistic equations of motion and cross sections for ionization and elastic scattering (also for relativistic energies). We also include our results for Bremsstrahlung. In our model we treat the produced photons as particles with constant velocity and take into account Compton scattering, pair production and photo ionization. We obtain the correlation between a negative stepped leader propagating upwards and the production of TGFs and positrons. Furthermore the direction of the photons and the positrons will be related to their energy. We will compare our results with results of other authors.

Our model is also applicable to the production of hard X-rays in streamer and leader discharges produced with Marx generators in the Megavolt range.

3. References

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