High-Energetic Radiation from Lightning and Laboratory Spark Discharge

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The pinch effect and the plasma focus conditions can be responsible for nuclear fusion reactions related with lightning phenomenon. The neutrons (2.45 MeV) and high energy protons (3.02 MeV) from lightning and thunderstorm can be produced in D–D nuclear fusion reactions. The high-energetic radiation from lightning and thunderstorm can be associated bought with proton capture and neutron capture. The photon energies in lightning gamma-ray spectrum can rise up to 19.8 MeV. The X-ray and gamma-ray signatures from lightning can be explained due to the Compton scattering effect. The collision of relativistic electrons with Krypton (Kr) and Xenon (Xe) as with metal vapor in the plasma discharge can intensify the X-ray emission due to their bigger atomic charge. The observation of the long period gamma ray radiation during the thunderstorm can be due to the decay of isotopes.

1. X-ray emission from laboratory spark discharge and rocket-triggered lightning

The laboratory spark discharge producing the X-ray radiation was done at the Technical University of Eindhoven in the Netherlands [1].

From the video (Fig. 1) one can see the plasma turbulence in the spark discharge and the very hot point on the grounded electrode visible for more then 5 ms. This overheated point can be the emitter of the metal vapor and the electron beam due to the thermo-electron emission. The role of the thermo-electron emission for formation of fast electrons flow was experimentally investigated and X-ray radiation was found at the initial stage of the spark discharge in the atmospheric air [2]. So the X-ray radiation with the source close to the grounded electrode can be due to the collision of fast electrons flow with atoms and ions [3].

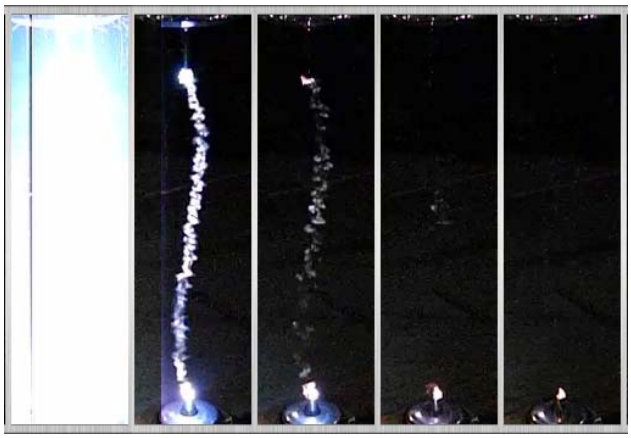

Figure 1. Plasma turbulence in the Spark discharge 1MV with 1m channel. Author's color video at 1200 fps taken on the camera Casio Exlim EX-F1 in the High-voltage laboratory at the Technical University of Eindhoven in the Netherlands (28 October 2010). Courtesy to A.P.J. van Deursen and C.V. Nguyen

That can explain that the X-ray bursts from rocket-triggered lightning done by Dwyer, J. R., et al. was from the altitude ~ 50 m from the ground [4]. The evaporation of the metal rocket trailing wire in spark discharge decrees the ionization potential and produces the heavy ions. The metal vapor and the atoms with bigger atomic charges are more effective for X-ray production [3].

2. Pinch effect and plasma focus conditions

The gamma-ray bursts with neutrons [5, 6, 7] appear not in every lightning discharge, they are rare in CG lightning and usually associated with intracloud lightning [8]. It is possible to explain this phenomenon by pinch effect or hot plasma instability with the plasma focus conditions in the compact area of plasma channel. The conditions for the pinch effect can be only in the case when the next lightning discharge goes in the same channel during the continuous current stage [3]. For the intracloud lightning the repetition rate can go up to some hundreds within ~ 100 μs, so the pinch effect can be common for them.

The CG lightning usually goes with lower rate of some events per second and choosing the new channel for the next stroke. But it can happen that CG lightning goes in the same channel within some ms twice. So for the CG lightning the probability of pinch effect is lower then for intracloud lightning. This fact can explain that a few CG lightning can produce X-rays and gamma-rays with neutrons and for the intracloud lightning the high energy photons and neutrons are common.

The lightning discharge consists from a big number of brunching dischargers. Each stroke enter the main plasma channel inject in it huge current (10–100 kA) within some nanoseconds. This is a well-known pinch effect that will significantly

increase the current density and the plasma temperature within some nanoseconds, so the possibility of the nuclear fusion reactions will appear [3]. The pinch effect can create instability of continuous gas discharge; it can be due to the current oscillations that lead to the plasma density variation, or turbulence in the hot plasma. The shock waives can appear cased by the pinch effect that can interrupt the current (within some nanoseconds) and the local breakdown will follow after that. The new strokes will enter the main plasma channel and this pinch sequence generation can follow for hundreds of times. This kind of hot plasma instability can create the plasma focus conditions in the compact area of plasma channel. The electric and magnetic fields in plasma focus are so huge that nuclear fusion reactions can go [3].

3. High-Energetic radiation from gas discharge

The first public announcement on the thermonuclear reactions in gas discharge was done by I. V. Kurchatov in his Speech at AERE/Harwell on 25th April 1956 [9].

The D–T, D–D and D–^{3}He reactions can go with the resulting energy barrier approximately from 100 KeV. We consider the D–D reactions going with the equal probability. The main outputs from the D–D Fusion reaction are proton 3.02 MeV and neutron 2.45 MeV. On the next stage the nuclear reaction can go in two different ways. The first one is the proton capture and the second is the neutron capture reactions.

The proton capture reaction is well known nuclear reactions of type (p, γ) and (p, α), so it can affect the chemical element and isotope structure of air gas mixture. The isotopes of Cl, K, F, Na, Br, Rb, I, Cs can appear in the proton capture reactions with Ar, Ne, Kr, Xe.

The neutron capture can go in reactions of type (n, n), (n, γ), (n, p), (n, α), ($n, 2n$). The absorption cross section is often highly dependent on neutron energy. So the fast neutrons (2.45 MeV) should be slowdown to the thermal neutrons in the reaction. In the wet air it is possible due to the reaction of type (n, n) on the atoms of ^{1}H, ^{12}C, ^{14}N, and ^{16}O. After that for the thermal neutrons are used, the process is called thermal capture. This reaction of type (n, γ) can go on ^{3}He, Kr, Xe and others isotopes with huge absorption cross section. Xenon-135 is a perfect neutron absorber due to its huge cross section for thermal neutrons 2.65 10^{+6} barns.

The production of protons 3.02 MeV and neutrons 2.45 MeV in D–D Fusion reaction together with proton capture and neutron capture reactions can explain the production of the radioactive materials, gamma-ray radiation and the air ionization during the lightning discharges within the thunderstorm [3]. The observation of the long period gamma-ray radiation during the thunderstorm can be due to the decay of isotopes [3]. The role of ^{3}He, Kr, Xe and others isotopes with huge absorption cross section is significant for the thermal neutrons capture [3]. The photon energies in gamma-ray spectrum can rise up to 19.8 MeV and the thermal neutrons will observed [3]. The X-ray and gamma-ray signatures from lightning can be explained due to the Compton scattering effect [3].

4. References

[1] C.V. Nguyen, A.P.J. van Deursen, Multiple X-Ray Bursts from Long Discharges in Air // J. Phys. D: Appl. Phys. — 2008. — Vol. 41. — P. 234012.

[2] Y.Y. Volkolupov, Y.E. Kolyada, M.A. Krasnogolovets et al., Formation of the High-Intensity Microsecond Flow of Electrons in the Channel of High Pressure Arc Discharge // Problems of Atomic Science and Technology. — 2000. — No 3. — Pp. 125–127.

[3] L.V. Sorokin, High-Energetic Radiation from Gas Discharge Associated with the Maximum Rate of Current Change // Bulletin of PFUR. Series Mathematics, Information Sciences, Physics. No 4, 2012. Pp. 181–188.

[4] J. R. Dwyer, H. K. Rassoul, M. Al-Dayeh et al., Measurements of X-Ray Emission from Rocket-Triggered Lightning // Geophys. Res. Lett. — 2004. — Vol. 31. — P. L05118.

[5] A. Shyam, T.C. Kaushik, Observation of Neutron Bursts Associated with Atmospheric Lightning Discharge // J. Geophys. Res. — 1999. — Vol. 104, No A4. — Pp. 6867–6869.

[6] G.N. Shah, H. Razdan, Q.M. Ali, C.L. Bhat, Neutron Generation in Lightning Bolts // Nature. — 1985. — Vol. 313. — Pp. 773–775.

[7] B.E. Carlson, N.G. Lehtinen, U.S. Inan, Neutron Production in Terrestrial Gamma Ray Flashes // J. Geophys. Res. — 2010. — Vol. 115. — P. A00E19.

[8] M.A. Stanley, X.-M. Shao, D.M. Smith et al., A Link Between Terrestrial Gamma-Ray Flashes and Intracloud Lightning Discharges // Geophys. Res. Lett. — 2006. — Vol. 33. — P. L06803.

[9] I.V. Kurchatov, On the Possibility of Producing Thermonuclear Reactions in Gas Discharge // Nucleonics. — 1956. — Vol. 14, No 18. — Pp. 37–42.