On atmospheric particle acceleration by lightning

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Conclusive data from ground-based stations, airborne detectors and satellites establish lightning and thunder-clouds as natural particle accelerators. During a winter thunderstorm in 2017, lightning struck near monitor sites at Kashiwazaki-Kariwa, Japan [1]. Enoto's team reports γ-rays above thresholds for neutron production in air by photonuclear reactions. After the γ-ray flash, line emission at 0.511 MeV followed for one minute.

In 1985 Shah et al. reported neutron counts from lightning at Gulmarg cosmic ray station in Kashmir, India. Still earlier Ashby & Whitehead detected 0.511 MeV photons during thunderstorm activity at Abingdon, UK.

State diagrams for cool, dense discharge plasma show an unstable sub-region due to quantum-mechanical exchange forces between conduction electrons, characterized by [2]:

Field threshold E_{th} Magnetic field London length Time scale

$$ne^2/80\pi\varepsilon_o^2 V_i \quad \approx 23 \text{ MV/m} \quad \mu_o I/2\pi R \approx 0.40 \text{ T} \quad \sqrt{(m/\mu_o ne^2)} \approx 1.1 \ \mu m \quad 4\pi e E_{th} R^2/\rho\kappa^3 \approx 230 \ \mu s$$

with e, ε_o, μ_o, electron mass m and quantum of circulation κ as fundamental constants. As material parame-ters we use density ρ=1.3 kg/m^3, channel radius R=5 cm, peak current I=100 kA and electron density n= 2.5×10^{25} m^{-3}for the lightning channel. Scale rules for photonic response in such lightning plasma accelerate ion circulation exponentially to levels for high-energy events. Ball lightning emerges as a charged eigenstate fully defined by its central potential, and evolving without change in radius and brightness [3].

As thermodynamic system we treat lightning plasma as elastic vortex system smoothly connecting helical strings as elementary unit, and circulating at the quantum limit. Unlike mechanical springs, we find their elastic forces independent of string length. We fit helical flux tubes interfering like worm gears in vortonic crystals packed with octahedral or icosahedral symmetry. We write internal energy in the fundamental form U(S,V), and obtain vortonic state equations for pressure and entropy as [2]:

Vortonic system Internal energy Pressure Entropy

State equation $U = S^{2/3}V^{1/3}$ P =-a/3T^2 S ? $S_0 = 2aV/3T^3$

with a and S_0 as positive integration constants. By contrast, corresponding expressions for classical particle and photon systems have positive pressure and positive powers of temperature. Thus our vortonic plasma states feature negative pressure for self-confinement, and irreversible evolution towards lower temperatures.

1 T. Enoto et al., *Photonuclear reactions triggered by lightning discharge*, Nature **551**, pp. 481–484, 2017.

2 G.C. Dijkhuis, *Helix string model for turbulent vorticity and cavitation in shearing arc plasma.*

Annals of the New York Academy of Sciences, Volume 891, pp. 259-272, 1999.

3 Idem, *Ball lightning as thermodynamic limit of the periodic system.* In: The Atmosphere and

Ionosphere, Editors V.L. Bychkov, G.V. Golubkov, A.I. Nikitin, pp. 331-355. Springer Books, 2010.