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A Model of the Turbulent Electric Dynamo in Multi-Phase Media

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Many terrestrial and astrophysical phenomena witness the conversion of kinetic energy into electric energy (the energy of the quasi-stationary electric field) in conducting media, which is natural to treat as manifestations of electric dynamo by analogy with well-known theory of magnetic dynamo. Such phenomena include thunderstorms and lightning in the Earth's atmosphere and atmospheres of other planets, electric activity caused by dust storms in terrestrial and Martian atmospheres, snow storms, electrical discharges occurring in technological setups, connected with intense mixing of aerosol particles like in the milling industry.
We have developed a model of the large-scale turbulent electric dynamo in a weakly conducting medium, containing two heavy-particle components. We have distinguished two main classes of charging mechanisms (inductive and non-inductive) in accordance with the dependence or independence of the electric charge, transferred during a particle collision, on the electric field intensity and considered the simplified models which demonstrate the possibility of dynamo realization and its specific peculiarities for these mechanisms. Dynamo (the large-scale electric field growth) appears due to the charge separation between the colliding and rebounding particles. This process is may be greatly intensified by the turbulent mixing of particles with different masses and, consequently, different inertia. The particle charge fluctuations themselves (small-scale dynamo), however, do not automatically mean growth of the large-scale electric field without a large-scale asymmetry. Such an asymmetry arises due to the dependence of the transferred charge magnitude on the electric field intensity in the case of the inductive mechanism of charge separation, or due to the gravity and convection for non-inductive mechanisms. We have found that in the case of the inductive mechanism the large-scale dynamo occurs if the medium conductivity is small enough while the electrification process determined by the turbulence intensity and particles sizes is strong enough. The electric field strength grows exponentially. For the non-inductive mechanism we have found the conditions when the electric field strength grows but linearly in time.
Our results show that turbulent electric dynamo could play a substantial role in the electrification processes for different mechanisms of charge generation and separation. Thunderstorms and lightning are the most frequent and spectacular manifestations of electric dynamo in the atmosphere, but turbulent electric dynamo may also be the reason of electric discharges occurring in dust and snow storms or even in technological setups with intense mixing of small particles.