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Comment on "A new model of charge transfer during ice–ice collisions" [C. R. Physique 3 (2002) 1293–1303] ☆

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Abstract

A model which proposes modifications of a theory of collisional charging of ice is criticized. ***To cite this article: J.G. Dash, J.S. Wettlaufer, C. R. Physique 4 (2003).***

Résumé

Commentaire sur « Un nouveau modèle décrivant le transfert de charge lors d'une collision entre particules de glace ». On critique un modèle qui propose quelques modifications d'une théorie sur les échanges de charge par collisions dans la glace. ***Pour citer cet article : J.G. Dash, J.S. Wettlaufer, C. R. Physique 4 (2003).***

The article [1] by M. Baker and J. Nelson (BN) appeared in a special issue devoted to contributions presented in a small Workshop on The Physics of Thundercloud and Lightning Discharge, described in a foreword to the issue given by one of the authors [2]. BN adopt the general outlines of the theory by Dash, Mason and Wettlaufer (DMW) [3], but modify it in certain details, and offer it as a new model. In the following we give a summary of the original theory, the modifications of the BN model, and our criticism.

DMW consider collisional charging a three stage process. The first stage is vapor growth of ice particles before collision, which causes kinetic roughening. The growth is treated as a competition between vapor deposition and surface diffusion, leading to a quantitative gauge of roughening. Ionization of water molecules is enhanced on the thus roughened surfaces. Because the OH^- ions remain bound to the surface while positive ions migrate into the ice crystal, a charged double layer is formed. The grain boundary area is proportional to the deposition rate of new molecules, and because the OH^- ions are localized at the grain boundaries, the surface charge density, and hence contact potential, is proportional to the growth rate. The second stage is an ice–ice collision, where a temporary liquefaction is caused by the inelastic energy loss. Melting liberates the negative surface ions into the melt liquid where their diffusion away is enhanced, but the major fraction of the positive ions remain in the crystal. The third stage is separation, when the two particles take roughly equal shares of the melt liquid. Thus, the particle that had the greater roughening, and hence growth rate, loses net negative charge. DMW obtain quantitative agreement with a detailed experiment [4].

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The BN model differs in the following respects:

(a) Vapor growth produces well faceted crystals;
(b) Collisions cause pressure melting;
(c) In collisions between a sharp point and a flat (rimed) surface, pressure melted liquid is driven from the former to the latter.

We do not accept the mechanism (a) as valid under the conditions of the experiments, but in the interests of brevity we focus on (b) and (c).

Considering (b), we agree that the collisions in question can produce large temporary pressures, which *in equilibrium conditions* would cause pressure melting. However, collisional melting requires latent heat input during the collision. Under adiabatic conditions the heat must be supplied from the enthalpy of the melted material and nearby regions. A theoretical estimate for the time of collision is made using the approach by BN (their Ref. [23]), yields an estimate on the order of 10^{-4} ms for a range of ice particle sizes and approach speeds. The required heat flux over the length scale of the active region leads to a temperature difference greater than 100 K, which is larger than either particle can provide.

We also find that (c) is invalid. An expression for the pressure distribution between colliding particles can be obtained according to the theory in the same section of the text cited by BN (their Ref. [23]) to estimate collision times. This analysis shows that the contact between two particles is a plane with circular perimeter, regardless of any difference in size, and the radial gradient of the normal pressure in the contacting region is the same for both.

References

[1] M.B. Baker, J. Nelson, A new model of charge transfer in ice–ice collisions, C. R. Physique 3 (2002) 1293–1303.
[2] M.B. Baker, A. Bondiou-Clergerie, Foreword, C. R. Physique 3 (2002) 1273–1275.
[3] J.G. Dash, B.L. Mason, J.S. Wettlaufer, Theory of charge and mass transfer in ice–ice collisions, J. Geophys. Res. 106 (2001) 20395–20402.
[4] B.L. Mason, J.G. Dash, Charge and mass transfer in ice–ice collisioms: experimental observations of a mechanism in thunderstorm electrification, J. Geophys. Res. 105 (2000) 10185–10192.