The term "Coulombic viscosity" is introduced here to define an empirically observed phenomenon from experiments conducted in both microgravity, and in ground-based 1-g conditions. In the latter case, a sand attrition device was employed to test the longevity of aeolian materials by creating two intersecting grain-circulation paths or cells that would lead to most of the grain energy being expended on grain-to-grain collisions (simulating dune systems). In the areas in the device where gravitationally-driven grain-slurries recycled the sand, the slurries moved with a boundary-layer impeded motion down the chamber walls. Excessive electrostatic charging of the grains during these experiments was prevented by the use of an a.c. corona (created by a Tesla coil) through which the grains passed on every cycle. This created both positive and negative ions which neutralized the triboelectrically-generated grain charges. When the corona was switched on, the velocity of the wall-attached slurries increased by a factor of two as approximately determined by direct observation. What appeared to be a freely-flowing slurry of grains impeded only by intergranular mechanical friction, had obviously been significantly retarded in its motion by electrostatic forces between the grains; with the charging reduced, the grains were able to move past one another without a flow "viscosity" imposed by the Coulombic intergranular forces.

A similar phenomenon was observed during microgravity experiments aboard Space Shuttle in USML-1 & USML-2 spacelabs where freely-suspended clouds of sand were being investigated for their potential to form aggregates. In this environment, the grains were also charged electrostatically (by natural processes prior to flight), but were free from the intervention of gravity in their interactions. The grains were dispersed into dense clouds by bursts of air turbulence and allowed to form aggregates as the ballistic and turbulent motions damped out. During this very brief (30-60 sec) damping period, motion of the grains was observed to be retarded by the electrostatic interactions. The fact that the grains almost instantly formed aggregates was evidence that their ballistic motions had been constrained and redirected by the dipole-dipole interactions that led to filamentary aggregate development (1,2). Undoubtedly, the "Coulombic viscosity" of the cloud assisted in damping grain motion so rapidly.

The electrostatically-induced grain-cloud viscosity or drag exerted on grain motion, is a complex function of three major parameters: charge magnitude, charge sign, and mean intergranular distance. The above experiments illustrate one particular type of granular behavior. The discussion here will therefore be restricted to drag relationships: (a) between grains that are naturally charged triboelectrically and thus exhibit dipole-dipole attractions between one another even if there are slight net charges present (which can be overwhelmed by dipole coupling at short distances), and (b) between grains that are densely spaced where the intergranular distance varies between zero and some value (usually tens or hundreds of grain diameters) that permits each grain to detect the dipole moment of another grain -- the distance is not so great that other grains appears as neutral electrical "singularities".

1. **Aeolian transport**: During motion of grains in a saltation cloud (on Earth, Mars, or Venus), triboelectric charging must occur as a result of multiple grain contacts, and by friction with the entraining air. A situation might develop that is similar to the one described above in the attrition device: grain motion becoming significantly retarded (reduced flux) as grains find it increasingly difficult to either separate from the surface, or to pass one another without Coulombic retarding forces. A "Coulombic drag" will exist at flux initiation and increase with time to work in direct opposition to the aerodynamic drag that drives the grain motion. It is predicted that this will lead to an increase with time of both the aerodynamic and bed-dilatancy thresholds (3). Because of Paschen discharge effects in the martian atmosphere, the electrostatic charging in a saltation cloud may be partially abated, but this will lead to greater grain mobility, more charging, and thus to a charge-discharge steady state mediated by mechanical interactions.
"Coulombic Viscosity" in Granular Materials: J.R. Marshall

II. Dry colluvial systems: Sand avalanches on dunes, dry debris flows, talus flows, avalanches, and pyroclastic surges are examples of gravity-driven, dense granular flows where rock/grain fragmentation and grain-to-grain interactions cause triboelectrification (sometimes augmented by other electrical charging processes), and where the grain densities of the systems are such that strong dipole-dipole interactions between grains might be expected to be present. Because it is expected that the Coulombic forces between grains will cause a sluggishness or enhanced granular-flow viscosity, the motion of a grain mass will be retarded or damped so that this will assist, ultimately, in terminating the flow. The greatest Coulombic viscosity will be created in the most highly charged systems, which will also be the most energetic. Thus, grain flows have some tendency to be self-limiting by internal energy partitioning; gravitational potential is converted to Coulombic potential, which manifests itself as a drag force between the grains.

III. Volcanic eruption plumes and impact ejecta curtains: The violence of these systems leads to powerful electrical charging of particulates. Lightning storms emanating from volcanic plumes are a testimony to the levels of charging. As pyroclastic grains interact forcefully and frequently within eruption plumes, it is reasonable to predict that the internal turbulent motions of the plume will be significantly damped by the Coulombic viscosity exerted by grain charges. Similarly, the high-velocity transport of ejecta caused by a meteorite impact should be subject to the conversion of kinetic energy into Coulombically-driven grain interactions that increase the viscosity of the debris cloud's motion.

IV. Protoplanetary disks and planetary rings: In both these systems, grains of all sizes are being gravitationally moved with speeds and directions commensurate with their size and position within the gravitational field. Hence, there are relative motions of grains with respect to one another. If the grains experience dipole-dipole interactions, these relative motions will be resisted, leading to an element of cloud viscosity caused by Coulombic forces. This will impact the behavior of the cloud, and thus influence the mode by which the ring particles interact, or the mode by which planetesimals form (3).

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