FILAMENTARY ION FLOW
There is nothing more uncommon than common sense.
Anonymous author

Because, up there, in heaven, isn’t paradise an immense library?
Gaston Bachelard (La Poétique de la rêverie)
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The arguments put forward by this book offer a coupled theoretical framework for an appropriate description and treatment of unipolar ion flows subject to electric fields. Several mechanisms can be adopted to generate ion flows, but exclusive reference is made here to those typical charge-injecting sources that are confined to overstressed (in an electrostatic sense) surface areas of conductors under direct current corona. The rationale for this choice is that a pair of main requirements for the physical phenomenon to be investigated, namely, generating ions and then setting them in motion by an impressed force, are met at once. The ion source identifies with an ionization region that occupies a restricted volume of space in contact with a conductor raised at a potential exceeding the corona onset level. Therefore, it could be said that the far broader drift region, where the repelled ions can slowly flow toward a collecting counterelectrode, covers the entire electrode gap. Under the described circumstances, and with special reference to the ion flow crossing the drift region, the governing electromagnetic and fluid dynamic laws form that special body of knowledge preferentially referred to as electrohydrodynamics (EHD). Given that there is a large amount of traditional and emerging practical applications somehow involving EHD applied to drifting ions (see later on), urgent improvements to available theoretical resources need to be made. Before going straight to the heart of the matter, it is positive to say a few preliminary words on the difficult task of finding a way of moving forward in the world of interdisciplinary investigations, where the present one is a prominent example. Any skillful and prudent researcher is aware of the fact that
carefully putting together a set of governing equations under the described complex situations could result in a very hard undertaking, sometimes exposed to misinterpretations and inconsistencies. The excuse for this difficulty resides in the need of getting, at first, information from broken up sections of physics before attaining a final joint model. It has been argued at times that a physical problem appears to be far too involved not owing to the true attributes of the overall system, but to the mathematical aspects of the defective model being profiled. Note further that a good grounding in reasoning on composite problems could in principle allow the emergence of some still submerged relationships between parameters that are traditionally pertaining to different areas of physics. Unfortunately, that is not really the case because when the departure between theory and experiment becomes a matter of some importance, the improving efforts often adopted by trial and error consist in supplementing the starting model with a number of higher-order terms. Such a commendable intention could result in a frustrating, unfruitful exercise because first-order interactions between parameters distinct from and usually handled in different compartments of physics still remain overlooked. These disappointing circumstances seem to characterize previous EHD approaches because the electromagnetic and fluid dynamic laws, somehow involved in the description of unipolar ion flows, are kept substantially decoupled. Very specifically, this is the case for the electric and velocity fields, enlivened in the ion-drift region, which are usually assumed to respectively exhibit divergence and circulation both different from zero. The real value of the present treatment essentially consists in highlighting the deficiencies commonly compromising EHD models and opposing them with a reformulated modeling that carefully takes into account mutual influences between the involved field laws. This revised approach distinctively applies in the drift regions because of the subsonic velocity of the ions flowing there. Indeed, all it requires is to only overcome some conceptual drawbacks resisting the explored hybridization. This will ultimately be expressed by the solenoidal and irrotational vector properties that, of necessity, the respective electric and velocity fields simultaneously should gain. Surprisingly and paradoxically, there is an added value to the given coupling: The complete governing formulation looks quite unsophisticated and eloquent to the benefit of physical interpretation. Especially in view of engineering applications, a recommended finishing touch is that of cautiously using Occam’s razor to cut out the often useless, confounding, and oversophisticated higher-order terms mentioned above. Consider that long-lasting laboratory tests and mature reflection on the supplied databases ultimately persuaded this investigator on the validity of the claimed hybrid model. The adopted theoretical scheme has been derived imparting, after R. E. Kalman, in that
lucid advice that reads “get the physics right, the rest is mathematics,” which is thus rather against the largely complied with and competitive advice that could read “get the mathematics right, the rest is physics.” The compelling attraction exerted by the latter approach is, in general, questionable since the adopted mathematical structures invariably work well only in the confined domains of physics where they were conceived. Instead, a correct mathematical approach to an integral reality needs to be founded on a common theoretical substrate whose specialized aspects are permissible to the extent that it holds unbroken.

Perhaps the more striking aspect of the present coupled treatment is that a subsonic ion drift is instead seen to assume the discontinued configuration of a filamentary flow guided by a Laplacian-field pattern. This issue is in contrast with previous uncoupled theories according to which a space-filling ion flow is claimed to cross the drift region under the action of a Poissonian electric field. The raised difference is, in this author’s opinion, the very cause of the commonly perceived departure between observables and theoretical predictions. This drawback is becoming increasingly unacceptable in view of the latest breakthroughs into avionics and turbomachinery, in relation to levitation or air propulsion by plasma actuators, and into geophysics and electromagnetic compatibility, in relation to ionosphere and pre-stroke mechanisms, to name just a few. Parenthetically, everything still remains to be done in evaluating whether this multichanneled corona-driven flow can be either fruitfully exploited in microfluidics—that is to say, as a substitute for diffusion-driven flow in microfluidic channels—or play a role in those geoelectric phenomena, classifiable as earthquake by-products, interfering with grounded sensitive systems. Even more traditional applications related to charge transfer—thus involving HVDC line environment, electrostatic precipitators, lightning protection systems, electrophotography, dry powder coating, ESD, ignition hazard, surface treatments of materials (fabric, etc.), and ozonizers—must be able to reap the benefits of research that has been carried out and reported in this book.

Several years ago, taking advantage of the sympathetic disposition of my collaborator Vitantonio Amoruso, I decided to bring together our experimental efforts to carefully understand the phenomenological aspects of the raised difficult problem. To this end, a patrimony of data, resulting from a three-decade activity developed in an ad hoc arranged department high-voltage laboratory, has organically been supplied. This has been made feasible by the special use of some unusual electrode assemblies. As a result, unexpected, submerged, or obliterated phenomena have been discovered and carefully taken into account in order for this unprecedented theory to be substantiated.

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