

Contact Charging Between Particles; Some Current Understanding

G.S.P. Castle

Department of Electrical and Computer Engineering
University of Western Ontario
London, ON, Canada
Email; pcastle@eng.uwo.ca

EXTENDED ABSTRACT

The presence of electrical charges resulting from surface contact of particles has many implications both in nature and industry. The mechanism(s) whereby these charges occur have been the subject of a number of studies that have been driven primarily by the need to accurately control these charges in modern applications such as electrophotography, powder coating, and materials separation as well as in industrial hazards. This presentation is an attempt to summarize current understanding of the factors affecting contact charging among small particles and to highlight where further work may be beneficial. A review of the literature shows that there is much variability in reported results. Many of the inconsistencies in this published data can be attributed to such things as surface and experimental variability, the nature of the contact, the charge species involved and the effect of charge back-flow [1]. However, notwithstanding these limitations there is general consensus that for conductors and semiconductors, contact charging may be fully explained by the theory proposed by Harper [2]. This states that when contact between surfaces occurs, thermodynamic equilibrium is established and this implies that free electrons are shared across the interface in proportion to the difference in the work functions of the two materials. The residual charge after separation was shown by Lowell [3] to be related to the product of the contact potential difference and the capacitance defined at a separation distance of about 1nm, where charge relaxation due to tunneling ceases. In practice contact charging is generally ignored when conductors are involved since the systems are usually well grounded. However, we have recently pointed out that this phenomenon can give rise to unexpected problems if contact and separation of small metal parts occurs in a situation where the parts may be collected in isolation from ground [4]. For the cases of insulator-insulator or insulator-conductor contact the issue is less clear since neither of these situations can give rise to thermodynamic equilibrium in the time scale observed for charge transfer. As a result it has been suggested that a number of electrons with high energy states can exist within the forbidden gap of an insulator but localized at the surface of the material [5-6]. This leads to the concept of an "effective" work function that may be considered as a surface rather than a bulk property of the ma-

terial. This is known as the Surface States theory of insulator charging which proposes that charges are exchanged between the surfaces in proportion to the difference between the effective work functions associated with the two materials. This theory has two limits; low and high density. For the former, charge transfer is limited by the finite number of high energy electrons present on the surface, for the latter, it is controlled by the electric field generated due to the transfer of charge across the interface. Although both limits have proponents, considerable evidence exists to support the validity of the high density limit. These include early experiments showing that an external electric field can control charge transfer between insulators and conductors in point contact [7, 8], extensive measurements on dual-component toner charging systems that agree with the high density theory [9], and the practical case of limiting the level of charge in powders flowing in pipes by using an electrified contact plate [10]. It is clear from these results that an electric field across the contact interface limits the amount of total charge that can transfer.

In spite of the convincing nature of this evidence, one ongoing puzzle has been the need for an explanation of the widely observed fact that charging occurs between particles within a poly-disperse mixture of a material having the same chemical composition and presumably the same value of effective work function [11]. In both nature and industrial practice it has been found that in such a mixture subjected to multiple surface contacts, the smaller fraction will usually have a resultant negative charge and the larger fraction a positive charge independent of the sign of the net charge of the mixture [12, 13]. Recently this question has been addressed by Lacks et. al. who used a probabilistic argument based upon the basic assumption of the Surface States theory [14, 15]. Their analysis uses the premise that particles in such a mixture will contain localized high energy state electrons that; a) are initially randomly distributed over the surfaces, b) initially have uniform surface density on all sizes of particles and c) that individual high energy electrons can be released to a vacant low energy state when random contact between surfaces brings them into close proximity. If the total surface area associated with the larger fraction exceeds that of the smaller fraction, as it normally does in poly-disperse mixtures, their analysis shows that this is sufficient to explain the observation of a net negative charge on the smaller fraction. In their model the simulation is run until most of the assumed high energy state electrons are exchanged. This corresponds to the low density limit. However, they also point out that no account is taken in the model for the electric field and/or electric discharge effects that may act to limit the magnitude of the charge exchange. This would correspond to the high density limit. It would be interesting to extend the analysis to include these effects and try to determine which limit best explains the magnitude of the charging. Also although the theory is stated in terms of electron transfer, the previous experimental work using toners suggests it should be equally valid for charging due to ion transfer. An interesting experiment would be to test a poly-disperse mixture of a given material treated with a positive charge control agent. In this case one would expect the smaller fraction to charge positively and the larger negatively.

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