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Discussions

Interactive comment on "A Comparison of Contact Charging and Impact Ionization in Low Velocity Impacts: Implications for Dust Detection in Space" *by* Tarjei Antonsen et al.

Anonymous Referee #2

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This manuscript presents model the combine the fragmentation of microparticles upon impact with a contact charging model, which is in turn compared to more conventional impact ionization model. I have a set of more general comments followed by specific comments. Based on the number and the of depth of the comments, I believe it is best for the manuscript to undergo a major revision and resubmitted.

General comments:

(1) The manuscript is somewhat difficult to follow and it is easy for the reader to get lost in the detail of the large number of assumptions made and models discussed. The recommendation is providing a high-level description of the charging model that is

straightforward to understand even for readers not immediately familiar with the field of impact ionization and/or the challenges of Faraday cup measurements from sounding rockets. This should be followed by the discussion of the details, including the arguments for the validity of the model over the entire range of parameters. An example of such parameter would be the validity of the model over the relatively large velocity range of 0.1 – 10 km/s, which I had a hard time to comprehend.

(2) The manuscript is missing an unambiguous description of the similarities and differences between the model introduced (fragmentation/capacitive charging model) and the more classical impact ionization model that it introduces. This has been confusing to me throughout the manuscript. In impact ionization, free charges are generated in the form of electrons and positively and negatively charged ions. The total charge of electrons and negative ions roughly equals that of the positive ions. The key from above is the that charges are in a free form, meaning that they can be extracted from the impact plasma. In comparison, the fragmentation model seems to keep the charges on the distribution on the fragments, i.e. not in a form of electrons and anions/cations. On the contrary, the contact charging between two materials would provide the particles preferentially with one polarity. It is not clear whether the manuscript is comparing apples to apples, meaning that the fragmentation model is really capable of describe some of the basic properties of impact ionization.

(3) This point is a follow-up for the comment above. As known and demonstrated, impact ionization also provides the means for analyzing the composition of dust particles. This is because the ions extracted from the impact plasma are characteristic to the composition of the dust material (and also that of the target). This fact has been greatly ignored by the manuscript, while one could argue that there is tremendous information in the composition of such ion mass spectra as a function of velocity. This has been investigated to detail by several authors, most notably by Fiege et al. and Hillier et al. Any model that is to update impact ionization needs to be consistent with such findings. It is recommended that the manuscript is extended by such discussion

(4) It appears that the manuscript is trying to apply the model over too large of a parameter space. The manuscript claims that the model applies over a wide impact speed range (0.1 – 10 km/s) and for a range of particles materials; from including icy grains metallic particles. I have a hard time believing that this is realistic (e.g. the normalized impact energy spans over 4 orders of magnitude). For example, at the low end of the speed range, a metallic particle could simply just deform (as a bullet from a rifle does). Is it possible that the model has enough free parameters that it can fit basically any experimental data, regardless of its physical validity? The recommendation here is provide a more detailed and more focused discussion why such model should be valid over such a wide range, and/or specify more carefully to what scenarios the fragmentation model is applicable to. (Apologies if I greatly misunderstood the manuscript. In this case, see comment #1.)

Specific comments:

- The abstract reads like a description of what the paper is about. Generally, the abstract is expected to be a short version of the paper. Revision is recommended. - Top of page 2. On the applicability of the Saha equation: To my best knowledge, every study on this topic has found Saha equation to be not applicable for impact ionization. Other than of course that (1) Ions of low ionization species have a large relative abundance in the impact plasma, and (2) elements (molecules) appear to have a velocity under which they are not found in the analyzed impact plasma. See, for example, the Fiege et al. papers. A revision is recommended. - Top of page 2: I believe the authors meant Auer 2001, instead of 2012. - Page 2: It would be good to clarify what contact charging means, meaning that fragments become charged? How does this comply with the current knowledge of impact ionization in terms of generating free charge carriers (electrons, atomic and molecular ions) and their composition, as discussed in the general comments? - Contact charging (or triboelectrification) has been extensively studied in the literature and providing some of the relevant reviews would be useful for the reader. - Section 2.1. The claim of the fragmentation of small particles (> 10 nm) is based on

two cited work. Froeschke et al. discusses the fragmentation of nanoparticle agglomerates. Tomsic et al. described the fragmentation of molecular ice clusters. Since both these works describe the fragmentation of rather fragile systems, it is not clear whether is truly appropriate to extrapolate these results to the fragmentation compact and refractory dust particles (e.g. metals, or rocky/mineral fragments), and over such large velocity range. The recommendation is to strengthen the arguments by providing a more detailed discussion. - Section 2.1. Sub-nano-scale particles are mentioned. The electronic properties consisting of tens or hundreds of atoms/molecules may be different from those of the bulk properties. For example, the work function. Is there size limit of validity that is worth mentioning? - Page 3. The paper claims to apply Hertz's law for elastic deformation is assumed 'for the impact energies encountered in this paper'. Not clear whether this is meant to apply for the entire 0.1-10 km/s impact speed range as stated in other parts of the paper. Please clarify. - Fig. 1 and relevant text: It was not too clear what is happening in this model. Is the particle only deforming or also fragmenting? Maybe I have missed it, but in any case, a high-level model description would be useful for the readers. - Page 4: Bin width of 0.01 nm (i.e. 10e-11m). That is smaller than the size of an atom and appears non-physical? Please clarify. - End of p. 4: Ztot charge – what sort of charge is this? Free or bound to the fragments? Is this the charge exchanged between the particle and the surface summed up for all fragments? Please clarify. - Wouldn't it be reasonable to assume that the fragmentation of the particle has a strong dependence on impact velocity? - Section 2.2. The expression of capacitance appears to have incorrect unit. This likely should be C = eps A/Z, rather than eps A Z. - Section 2.3. The two velocity regimes (5-10 km/s and > 10 km/s) are quoted as the two regimes of shock wave ionization. This is somewhat confusing wrt the work by Mocker et al., where the velocity threshold has been shown for which volume ionization is epexted to dominate. Which is, btw, outside of the interest of this manuscript that is limited to < 10 km/s. Can the authors provide some level of discussion and reference where for the two velocity ranges for shock-wave ionization are discussed? - Figure 4. Is it reasonable to assume that the work function of fragments as small as 0.2 nm will be similar to that of the bulk material? - Figure 4. This figure is confusing. How can the model assume that the particles are the same size (30 nm) throughout the entire velocity range shown? The nature of the accelerator's operation is such that larger particles have lower velocities and smaller particles can reach higher velocities. The normalized yield in the units of C/kg that considers the assumption that the charge yield scales with the mass. It is not clear if the fragmentation model would apply for the varying dust size of the experimental results. Has this been investigated? Is this figure really comparing apples to apples? Please clarify and provide the relevant discussion.

Tidbits:

- Is the quantization of the charge on the fragments considered? Small particles can carry only one elementary charge (or zero) and the total charge would be the statistical average over all particles. Please clarify or discuss as appropriate. This comment is relevant to equation A4 as well.

- It might be useful to note that the literature has already discussed the impact ionization of icy dust grains in relevance to the Cosmic Dust Analyzer measurements in Enceladus's plumes. Please see the papers by Postberg and Abel (some combination of these two authors, plus other coauthors). Basically, it has been found that the charge production in this case is best described by a MALDI-type process, where the preformed ions in the icy matrix are released by the impact of the particle and the evaporation of the ice. It might be beneficial to check the validity of the fragmentation model against these findings.

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