Energy loss due to plasmon excitation by the impact of charged particles on solid surfaces: Beyond an standard approximation

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Synopsis We demonstrate that a standard approximation in the integration conditions of the transferred momentum, which is frequently employed for the study of the interaction of charged projectiles with condensed matter, might lead to inconsistent results. We propose a method for avoiding these shortcomings. Finally we exemplify this issue by studying the excitation of bulk plasmons by a particle penetrating a semi-infinite material at an oblique trajectory.

The increasing improvement of spectroscopic techniques based on the interaction of charged particles with condensed matter leads to a continuous revision and refining of the theoretical models used to describe this process. In this framework, the study of plasmon excitation is of great relevance for the characterization of surfaces, thin films and nanomaterials. In this communication, we reevaluate a standard approximation in the integration conditions of the transferred momentum [1], which has been usually applied in the literature for more than forty years. We show that this approximation might lead to inconsistent results as, for instance, an spurious dependence of the excitation of bulk plasmons on the incidence angle θ for processes occurring deep inside the solid (see, e.g. [2], fig. 7a). Here we propose a method for avoiding these shortcomings of the standard approach, by employing the same integration conditions along every direction of the transferred momentum.

We exemplify this method by evaluating the energy loss rate $\mathrm{d}W/\mathrm{d}t$ due to bulk plasmon excitations for a particle of charge Z and velocity $\mathbf{v}$ entering into a semi-infinite material of a given dielectric function $\varepsilon(\mathbf{k},\omega)$. We define θ as the angle between $\mathbf{v}$ and the normal to the planar interfase. For the sake of simplicity, we employ a specular reflection model and an extended pseudo-medium method [3], being the generalization to more sophisticated theories straightforward. The electric potential is obtained through Poisson's equation in a Fourier transformed space, and its time derivative leads to the energy loss rate, from which we single out the bulk contribution [4].

In figure 1 we show $\mathrm{d}W/\mathrm{d}t$ at very large distance from the planar surface, well inside an aluminium sample, i.e. with a plasma frequency $\omega_p = 0.55$ a.u. We clearly see that our calculation leads to an energy loss rate which is independent of the angle, as expected. On the other hand, the use of the standard approximation leads to a spurious dependence with θ. A similar analysis for the production of surface plasmons is under way.

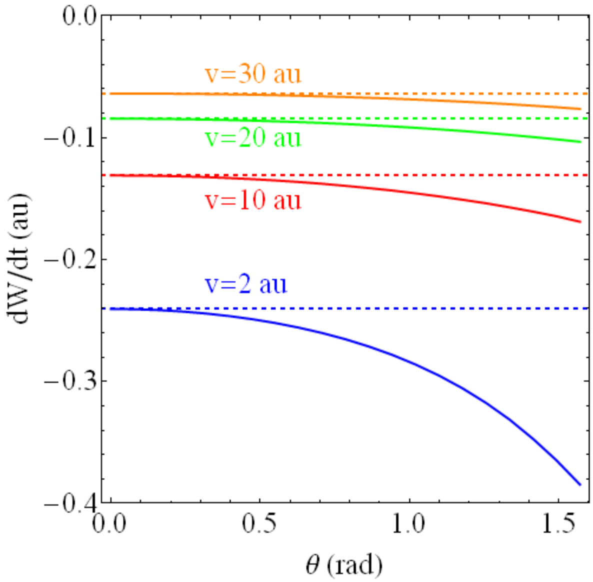

Figure 1. Energy loss rate $\mathrm{d}W/\mathrm{d}t$ due to bulk plasmon excitation for a particle of charge $Z = 1$ inside Aluminium, as a function of the incidence angle θ for various values of the velocity v. The present calculation (broken line) is compared with the standard model (full line), as described in the text.

References

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