J. Phys.: Condens. Matter 5 (1993) A299–A300. Printed in the UK

Evolution of an electron beam travelling parallel to a uniformly charged surface

Antonio Egea-Guillén†, Rafael Garcia-Molina† and Néstor R Arista‡

† Departamento de Física, Universidad de Murcia, Apartado 4021, E-30080 Murcia, Spain
‡ Centro Atómico Bariloche, División Colisiones Atómicas, RA-8400 Bariloche, Argentina

Abstract. We discuss the behaviour of an electron beam running parallel to the flat surface of a metal or dielectric.

Recent scanning transmission electron microscopy (STEM) experiments [1] suggested the possibility that an electron beam running externally and parallel to the flat surface of a metal or a dielectric may strongly be deflected towards that surface. However, theoretical calculations of the image force [2–6] did not predict such a strong deflection. The possibility of explaining this deflection as being due to surface charge effects was left as an open question.

In this work we discuss the behaviour of an electron beam which moves through the vacuum parallel (in the y direction) to a uniformly positive-charged surface (defined by the xy plane). The beam movement along the y axis corresponds to that of a free wave, since the force felt by the beam only depends on the z distance to the surface. We shall assume that the incident beam has a cross section with a Gaussian intensity distribution, and that it cannot penetrate through the material surface (see the inset in figure 1). The Gaussian cross section of the electron beam is characterized by its mean z_0, which represents the distance from the surface to the centre of the beam, and by its variance σ^2, which is related to the width of the beam.

To take into account the interaction of the beam with the charged surface we approach the beam wavefunction by a linear combination of the eigensolutions corresponding to an electron at a generic distance z from the surface:

$$\Psi(z,t) = \sum_n a_n \Phi_n(z)\, \mathrm{e}^{-\mathrm{i}E_n t} \tag{1}$$

where a_n are the coefficients of the development and $\Phi_n(z)$ are the eigenfunctions of an electron in a homogeneous electric field [7]:

$$\Phi_n(z) = \mathrm{Ai}[z(2\mathcal{E})^{1/3} - E_n(\sqrt{2}/\mathcal{E})^{2/3}]. \tag{2}$$

In the above expression $\mathrm{Ai}(\zeta)$ is the Airy function [8], $\mathcal{E}$ is the electric field due to the surface charge distribution and E_n are the energy eigenvalues corresponding to each eigenstate, and are related to the zeros λ_n of the Airy function through $\lambda_n = E_n(\sqrt{2}/\mathcal{E})^{2/3}$. Note that atomic units are used throughout this work.

Equation (1) allows us to calculate, after a time t, the evolution of the electron beam cross section while travelling over the charged surface. We have calculated the a_n coefficients in (1) by adjusting $|\Psi(z, t = 0)|^2$ to a Gaussian beam with $z_0 = 35$ and

0953-8984/93/ SA0299+02$07.50

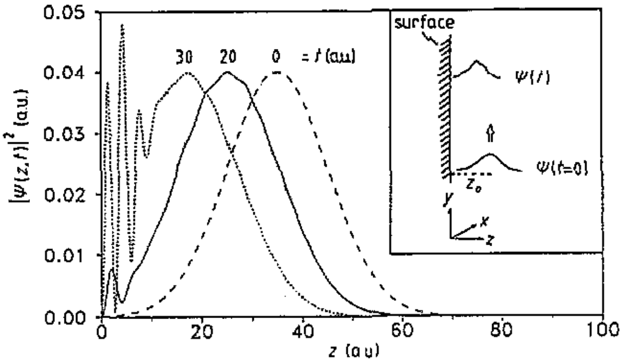

Figure 1. Intensity profile, represented at three different times, of the electron beam in the direction transversal to the movement. The inset shows the beam wavefunction position with respect to the surface. (See main text for more details).

$\sigma = 10$ moving in an electric field $\mathcal{E} = 4 \times 10^{-2}$, which are the approximate values that can be derived from Cowley's experiment [1]. Our results for the evolution of the transverse profile of a 100 keV beam are presented in figure 1 for different times; as can be seen, at $t = 0$ we have a well shaped Gaussian beam, which moves towards the surface as time increases, but losing its Gaussian form and giving rise to oscillations in the proximity of the surface. These oscillations are larger as the beam becomes closer to the surface and can be understood as being due to interference effects between the reflected and the deflected parts of the wave. This quantum mechanical description of the problem will allow us to follow the evolution of the beam cross section while interacting with the target surface. We hope this method will be useful to analyse experiments of the type reported by Cowley [1]; a specific application to this case is currently been considered.

Clarifying discussions with Professor M Ortuño are greatly appreciated. Financial support was provided by the Spanish DGICyT (projects PS89-0065 and PS90-0077).

References

[1] Cowley J M 1984 *Ultramicroscopy* **14** 27
[2] Echenique P M and Howie A 1985 *Ultramicroscopy* **16** 269
[3] Garcia-Molina R, Gras-Martí A, Howie A and Ritchie R H 1985 *J. Phys. C: Solid State Phys.* **18** 5335
[4] Rivacoba A and Echenique P M 1988 *Ultramicroscopy* **26** 389
[5] Zabala N, Rivacoba A and Echenique P M 1989 *Surf. Sci.* **209** 465
[6] Martínez-Torregrosa A, Garcia-Molina R and Gras-Martí A 1990 *Ultramicroscopy* **34** 283
[7] Flügge S 1974 *Practical Quantum Mechanics* (Berlin: Springer) problem 40
[8] Abramowitz M and Stegun I A (eds) 1972 *Handbook of Mathematical Functions* (New York: Dover) ch. 10