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A FLUID ANALYSIS OF ELECTRON RESONANCES AND NON-LOCALITY IN GASES

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The origin of periodic electron spatial structures in gases subject to *spatially uniform* electric fields E_0 has been recently analyzed through fluid equations [1] thereby providing greater physical understanding of the 'window' phenomenon in the Franck-Hertz experiment, and complementing the more accurate but purely numerical results provided by Boltzmann's equation [2]. Similar physical insight can be obtained for a *spatially varying* electric field, which modulates electron properties substantially if the applied wavelength matches the natural, 'Franck-Hertz' wavelength, simultaneously producing large phase shifts ('non-local effects'). Such cases have been analysed extensively through solutions of the Boltzmann equation [3] but never by physically tenable, benchmarked fluid modeling as described in [1, 4].

In this paper we extend Ref [1] to consider electrons initially distributed uniformly in an infinite gas, $-\infty < z < \infty$, with no sources or boundaries, and subject to a uniform field E_0. A small space-dependent field $E_1(z) << E_0$ is then switched on, giving a combined field

$$E(z) = E_0 + E_1(z) \tag{1}$$

and this in turn perturbs the electron properties. Eventually a new steady state is reached in which perturbations in particle properties, e.g., average electron velocity, are of the form

$$v(z) = v_0 + v_1(z)$$

where

$$v_1(z) = \int_{-\infty}^{\infty} \mu(z-z') E_1(z')\, dz' \tag{2}$$

is a non-local constitutive relation (Ohm's law) between the cause (the field at z') and the effect (velocity perturbation at z). General, analytic expressions for the 'mobility' function $\mu(z-z')$ will be given, and circumstances discussed for the validity of the 'local' approximation $\mu(z-z') \approx \mu_0\, \delta(z-z')$.

Non-locality and resonances are clearly illustrated in Fig. 1 which shows the response to a small gaussian disturbance of appropriate width for a neon model. This result is semi-quantitatively similar to that obtained by Ref [3] who solve the Boltzmann equation for a large gaussian field-pulse.

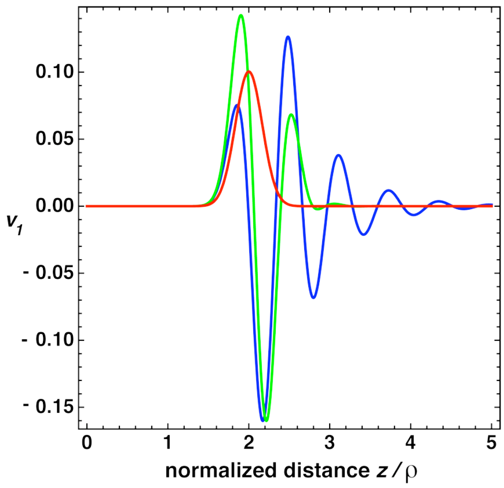

Figure 1: Response $v_1(z)$ to a gaussian disturbance $E_1(z)$ (red curve) centered at $z/\rho=2$. The blue and green curves are for E_0/N =18 Td (inside the Franck-Hertz 'window') and E_0/N = 40 Td (outside the window) respectively

The present paper is about electron *swarms* in an externally prescribed electric field, but the analysis nevertheless carries over to self-consistent fields in the plasma scenario. Since *both electrons and ions* must then be considered together in conjunction with Poisson's equation [4], a physically tenable, benchmarked fluid model of the ion component is also required. As for electrons, it is generally incorrect to assume that ions can simply be described by Fick's law and a diffusion equation.

References

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