An analogy between the Miller force and high-frequency diffusion

I. D. Kaganovich

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The high-frequency diffusion coefficient is an important parameter in microwave discharges at moderate pressures.[1] Several different interpretations have been given to this parameter.[1,2] It will be shown below that this phenomenon has a clear physical analogy: the Miller force in the collisionless case (when the microwave field frequency is $\omega \ll \nu$, where ν is the collision frequency of electrons with neutral particles). A difference is that in the collisional case the position dependence of the phase, rather than that of the field amplitude, must be taken into account to obtain the avenge motion. For simplicity we consider the case when the collision frequency of electrons with gas particles is independent of energy. Then for each electron the equation of motion in the field $E_0(x)e^{i\omega t+\phi(x)}$ can be written in the form

$$(i\omega+\nu)\dot{x}=(e/m)E_0(x)e^{i\omega t+\Phi(x)}. \tag{1}$$

The weak inhomogeneity of the field amplitude and phase leads to an average drift of electrons in time; the average force acting on an electron is

$$F=\frac{e}{m}\left\langle\left(\frac{\partial E_0(x,t)}{\partial x}\xi+E_0(x,t)\frac{\partial\Phi}{\partial x}i\xi\right)\right\rangle,$$
$$\xi=eE_0(x,t)/mi\omega(\nu+i\omega), \tag{2}$$

where $\langle\ \rangle$ denotes an average and ξ is the displacement of the electron at frequency ω.

After performing the average we obtain for the average force on an electron

$$F=\frac{e^2}{2m}\left(\frac{1}{2(\nu^2+\omega^2)}\frac{\partial E_0^2}{\partial x}+\frac{\nu E_0^2}{\omega(\nu^2+\omega^2)}\frac{\partial\phi}{\partial x}\right). \tag{3}$$

If the motion can be treated as collisionless we obtain the Miller force, otherwise we obtain high-frequency diffusion. Indeed, for a given high-frequency current (consisting of the displacement and conduction currents):

$$j_0e^{i\omega t}=\frac{e^2nE}{m(\nu+i\omega)}+\frac{i\omega E}{4\pi}, \tag{4}$$

the phase difference between the current and the field is

$$tg\Phi=\omega(\tau-\nu^{-1}),$$
$$\tau=\frac{m(\nu^2+\omega^2)}{4\pi e^2n\nu} \tag{5}$$

and the flux of electrons is

$$n(\dot{x})=\frac{nF}{\nu m}=-\frac{1}{2}\frac{v_{gp}\tau\ \partial n/\partial x}{1+(\omega(\tau-\nu^{-1})^2},\qquad v_{gp}=\frac{eE_0}{m\sqrt{\nu^2+\omega^2}}. \tag{6}$$

When

$$\omega\tau\ll 1,\qquad \omega/\nu\ll 1. \tag{7}$$

We obtain the well-known expression for the high-frequency diffusion coefficient of the electrons

$$D_{\mathrm{HF}}=D_e\frac{\langle E^2(x,t)\rangle}{nT_e} \tag{8}$$

where D_e is the electron diffusion coefficient. When either of the inequalities in (7) is not satisfied, high-frequency diffusion is strongly suppressed.

[1] G. I. Shapiro and A. M. Soroka, *Pis'ma Zh. Tekh. Fiz.* **5**, 129 (1979) [*Sov. Tech. Phys. Lett.* **5**, 51 (1979)].
[2] E. P. Velikhov, A. S. Kovalev, and A. T. Rakhimov, *Physical Phenomena in a Gas-Discharge Plasma* [in Russian], Nauka, Moscow (1987).

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