Comment on "Highly nonlinear, sign-varying shift of hydrogen spectral lines in dense plasmas"

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Possible inconsistencies between the recent hydrogen H_α spectral line shift measurements and modifications of the theory of these shifts by Escarguel *et al.* [Phys. Rev. E **62**, 2667 (2000)], and earlier measurements in dense plasmas and corresponding calculations are discussed. Some of the claimed differences may likely be due to underestimates of Debye shielding effects and to differences between definitions of line shifts in the case of asymmetric profiles.

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In a recent paper [1], Escarguel *et al.* state that measured redshifts of the hydrogen H_α spectral line in their underwater, laser spark experiment are only half of those predicted by calculations [2,3]. However, the ratio of these shifts to the FWHM (full widths at half maximum) measured [4] in the same spark apparatus, namely 0.08 ± 0.02 at electron densities of $(2–3)\times10^{18}\ \mathrm{cm}^{-3}$, is similar to that in a high temperature gas-liner experiment [3]. The temperatures were higher by a factor of ~10 in the earlier work [3], resulting in very similar linewidths to those in [1] at a given density according to (extrapolated) full computer simulations [5]. However, the shifts according to Refs. [2] and [3] are expected to increase with temperature. The relative shifts, in terms of the widths, are therefore not at all surprisingly small in the experiment, suggesting that the absolute values correspond to a lower electron density than had been inferred, e.g., from the widths of the $4s$-$4p$ K I lines. This could well be related to the fact that the experimental data were averages over "thousands of successive signals to improve the signal-to-noise ratio" [4], i.e., to lack of repeatability or to insufficient time resolution. Were the actual densities in the spark experiments smaller by a factor close to 2, the measured shifts would in fact be consistent with previous calculations [2,3]. (Unfortunately, neither the paper under comment here, nor previous papers [4,6] on the underwater spark, contain any experimental data for the lines used in the density determinations.)

As to the theoretical modifications proposed by the authors [1], they begin in their Eq. (1) as in a previous paper [7], with a formula for the electron-impact shift of a particular Stark component. This formula was originally derived by Sholin, Demura, and Lisitza [8] assuming purely binary collisions. However, the same authors [8] also stated that their shifts d_n are reduced by a factor $(n^2a_0N^{1/3})^{1/2}\approx0.2$ if Debye shielding of electron collisions were allowed for; they concluded "that in the dipole approximation we indeed have, in fact, $d_n\approx0$." (Here $n=3$ is the principal quantum number and N the electron density.) Another estimate of this reduction factor can be obtained by using the second-order perturbation theory result [Eqs. (151) and (161b) of [9]] for electron-collisional shifts in terms of the characteristic functions $b(z)$, i.e., $d_n\sim b(z_{\min})-b(z_{\max})$, with $z=\Delta\omega\rho/v$ in terms of (Stark) level splittings $\Delta\omega$, limiting impact parameters ρ and electron velocity v. For the small $z_{\min}$ values relevant here, we can use $b(z_{\min})=\pi/2$ (the high temperature limit), while for $b(z_{\max})$ we may use Eq. (161b) of [9] to obtain a reduction factor $2z_{\max}K_0(z_{\max})I_1(z_{\max})\approx z_{\max}^2|0.577+\ln(z_{\max}/2)|$ in terms of modified Bessel functions K_0 and I_1 (and their small z expansions). For $z_{\max}$, a reasonable choice for the relevant level splitting is the half width at half maximum (HWHM), while the thermal average of $v/\rho_{\max}$ for Debye shielding corresponds to the electron plasma frequency ω_{pe}. This gives $z_{\max}\approx0.24$ for the experimental conditions and therefore a reduction factor of 0.09, even smaller than the original estimate [8]. Evidently this Debye shielding effect was underestimated even more in [7], which most likely invalidated the estimates of the "highly nonlinear, sign-varying shift" (called the "dipole ionic-electronic shift" or DIES). Probably this underestimate is related to the difference between center of gravity shifts as calculated in [1] and [7] for asymmetric line profiles and measured shifts obtained from fits to symmetric profiles in regions near the intensity peak. (The latter definition had to be used in all experiments discussed here, including [1], because of the strong background continua.) The reader may finally notice that the $\Delta n=0$ shift contributions in Ref. [2], estimated according to Ref. [10], are also nonlinear (but not sign-varying), as are those of Könies and Günter [3], basically due to Debye shielding [see, e.g., Eq. (9) of Ref. [2]].

The red shifts calculated including the DIES blue shifts are thus most likely underestimated by at least 20% due to Debye shielding of electron collisions and probably by more than that from the inclusion of an effect due to the "acceleration of the perturbing electrons by the ion field," called AEIF [11]. This effect supposedly also reduces the shifts [1], but may have been overestimated judging by the experience with corresponding effects on the widths. (See below; also, from the theoretical temperature dependence [2,3] mentioned above, the acceleration would actually be expected to result in increases of the shifts.) Instead of the reduction factors 1.4–1.5 for the shifts from the AEIF effect, an improved theory or, more likely, a future full computer simulation, allowing also for shifts, is thus likely to yield much smaller reduction factors for shifts in the central region of the line. For the widths this can already be seen by comparing the advanced general theory results [1] with the full (electrons and ions) simulations by Gigosos and Gardenoso [5]. In any case, the underwater spark measurements [1] may in fact be consistent with the earlier calculations of the shift [2,3], as are recent measurements in the high-temperature gas liner experiment with smaller hydrogen concentrations to reduce the optical depth [12]. Finally, there are the measurements on a laser-driven pressure cell [13] at about twice the temperatures in [1] and densities up to $10^{20}\ \mathrm{cm}^{-3}$ (corresponding to ion-ion coupling parameters $\Gamma \lesssim 0.5$), which also yield shift-to-(FWHM)width ratios close to 0.1 in agreement with extensions of the theory of Könies and Günter [3]. Comparison with the earlier shift calculations [2] is not possible, because Debye screening of the (dominant) $\Delta n \neq 0$ interactions was neglected there. Corresponding corrections would, of course, enhance the nonlinearity and remove the deviations between the gas-liner measurements [3,12] and [2] for densities above $3\times 10^{18}\ \mathrm{cm}^{-3}$.

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