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Authors

Cooper, William S.
Hicks, William W.

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USE OF THE HIGH FREQUENCY STARK EFFECT IN PLASMA DIAGNOSTICS*

William S. Cooper III and William W. Hicks

Lawrence Radiation Laboratory
University of California
Berkeley, California, 94720

July 23, 1970

We use new numerical calculations of the high frequency Stark effect in He I to estimate the range of validity of similar calculations based on perturbation theory and point out pitfalls in using this effect in plasma diagnostics.

The high frequency Stark effect in He I, which produces "satellites" of allowed and forbidden spectral lines, is a nonperturbing means of determining the frequency, intensity, and direction of oscillating electric fields in plasmas. Most of the work reported to date relies on second order time-dependent perturbation theory,[1-3] or modifications of it.[4,5] In anticipation of the increased application of this technique in the future to plasma heating experiments in which perturbation calculations are no longer adequate (this situation may already occur in some experiments[5]) we have extended the method of Autler and Townes,[6] a numerical solution of the time-dependent Schrödinger equation, to include the effects of a magnetic field[7] and of multiple interacting levels. This work will be reported in a later publication; in the meantime we wish to point our several pitfalls in the use of the high frequency Stark effect in plasma diagnostics which have become apparent in comparisons of our numerical calculations with those based on perturbation theory.

(a) We have calculated a number of high frequency Stark patterns of the 4922-Å He I line (2^1P-4^1D) to estimate the range over which the Baranger-Mozer theory[1] correctly predicts the satellite intensities. If we keep ν, the frequency of the electric field, constant and increase the field strength, the intensities of the two satellites grow, but at rates which differ increasingly from predictions based on perturbation calculations; higher order satellites and Stark shifts, neither predicted by the Baranger-Mozer theory, also become important. As pointed out by Kunze et al.,[5] the near satellite is less reliable than the far satellite as an indicator of the electric field strength. Our calculations on the 4922 line indicate that the second-order perturbation theory gives the ratio of the intensity of the far satellite to that of the allowed line with an error of less than 30% as long as $E_{rms} < 10$ kV/cm and $25 < \nu < 120$ GHz. When perturbation calculations fail, higher-order satellites with intensities comparable to those of the original pair of satellites are also present in the pattern. If the field strengths are so large that the Stark shifts greatly exceed the unperturbed separation between upper levels one should use the theory of Blochinzew.[8]

(b) At field strengths above a few kV/cm, and for lines likely to be used for diagnostics (4388-, 4922-, and 4471-Å He I), the Stark shifts of the levels may confuse measurement of the electric field frequency. Their inclusion would, for instance, considerably modify the interpretation of at least one recently published observation of plasma satellites.[5] Stark shifts of energy levels actually provide a simple way to measure the rms electric field strength. Computer calculations of the satellite pattern of the 4922 line indicate that the Stark shifts of the 4^1D and 4^1F levels are essentially independent of the electric field frequency. We define the net Stark shift Δ to be the separation of the (shifted) allowed line from the average of the positions of the "far" and "near" satellites minus 1.364 Å, the calculated separation in the absence of an electric field based on a new determination of the 4^1F term value by Martin.[9] Approximate expressions for Δ for the 4922 line, in Å, as a function of the rms electric field strength in kV/cm, are $\Delta \approx 0.0095\, E_{\mathrm{rms}}^2$ for $E_{\mathrm{rms}} < 3$ kV/cm, and $\Delta \approx 0.0133\, E_{\mathrm{rms}}^{1.71}$ for $3 < E_{\mathrm{rms}} < 10$ kV/cm.

(c) In some cases one must consider more than two upper levels. For example, our computer calculations predict and experimental observations on the 4388 line (2^1P-5^1D) for $\nu = 35.2$ GHz, $E_{\mathrm{rms}} = 3.5$ kV/cm confirm that the 5^1G level introduces new satellites and strongly affects the positions and intensities of those originating from the 5^1D and 5^1F levels.

(d) A magnetic field produces a Zeeman pattern of the satellites which has recently been calculated and observed.[7,10] A magnetic field can be included in the perturbation calculations; its effect is to increase the intensity of a satellite (sum of all Zeeman components) by a factor

$$F_\pm = \frac{4\cos^2\gamma(6+\sin^2\theta) + \sin^2\gamma(13+\cos^2\theta)\left[\left(\frac{\Omega \pm \omega}{\Omega \pm \omega + \omega_L}\right)^2 + \left(\frac{\Omega \pm \omega}{\Omega \pm \omega - \omega_L}\right)^2\right]}{4\cos^2\gamma(6+\sin^2\theta) + 2\sin^2\gamma(13+\cos^2\theta)}.$$

Here γ is the angle between $\vec{B}$ and $\vec{E}$ ($\vec{E}$ is assumed to be random in azimuth), θ is the angle between $\vec{B}$ and the direction of observation, Ω

is the unperturbed separation between upper levels, ω is the field frequency, and ω_L is the Larmor frequency. If $\vec{E}$ is random, $\cos^2\gamma$ and $\sin^2\gamma$ should be replaced in this expression by their spatial averages 1/3 and 2/3.

FOOTNOTE AND REFERENCES

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