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A critical analysis of the advanced generalized theory: Applicability and applications

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Abstract

A recent series of theoretical works (“advanced generalized theory”) has been proposed and applied to the analysis of hydrogen lines, particularly H_α in plasmas. The “advanced generalized theory” (AGT) [JQSRT 1994;51:129, Phys Rev E 1999;60:R2480, JQSRT 2000; 65:405] is critically examined, both theoretically and in applications to the analysis of experimental data. A number of serious flaws are exposed and discussed. The major flaws include using an inconsistent perturbation theory and erroneous Weisskopf radius-type arguments to access dynamic behavior. Further, the results derived from calculations using the theory are in disagreement with both exact analytic results and benchmark calculations giving rise to the conclusion that the theory is not physically valid. Finally, we find that applications of this theory to laser-spark and flash-tube experiments have led to claims of warm dense matter (WDM) effects, which are found here to be unnecessary when experimental errors are estimated realistically. In summary, we find the AGT to be incorrect in it formulation, incorrectly reduced to numerical results, and inappropriately applied to data analysis.

Keywords: Stark broadening; Hydrogen

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1. Introduction

In recent years, the "advanced generalized theory" (AGT) [1–3] has been invoked to propose new high density effects for hydrogen line broadening calculations and claims have been made for agreement with various high density hydrogen experiments [1,2,4]. The AGT uses a parabolic basis and, as we shall illustrate, this and many other aspects of the formulation indicate that it is not general, in the sense of generally applicable. Indeed, more generalized approaches to spectral line broadening in plasmas exist in the literature and take many forms: the Pfennig–Lisitsa–Sholin (PLS) [5,6] approach which is an analytical, fully nonperturbative, solution of the time-dependent Schrödinger equation; the unified theory [7,8]; and the joint electron–ion simulations [9,10]. Further, we note that a critical measure of the validity of a theoretical formulation, which is found in all the theories mentioned as well as the standard theory (ST) [11,12], is a consistency in the assumptions and approximations employed. Here we will examine in detail the basic premises of, and results derived from, the AGT.

The AGT includes within its framework three components. The first of these components is the generalized theory (GT), which attempts to solve the impact broadening problem in the interaction picture with an unperturbed Hamiltonian consisting of the atomic Hamiltonian, the quasistatic ion microfield, using the Stark basis, and the component of the electron field along the quasistatic ion microfield direction. The second component is a residual ion impact width employed for all densities. The third component is a reduction of the electron impact broadening due to the acceleration of the perturber in the field of the nearest-neighbor ion to the emitter. We will analyze these components in the following sections.

2. Analysis of the original generalized theory (GT)

The idea behind the GT [1] is to solve the collisional broadening problem in the interaction picture with the unperturbed Hamiltonian consisting of the atomic Hamiltonian, the quasistatic ion field (i.e., the Stark basis), and the electronic field component in the direction of the quasistatic field. That is, the AGT essentially includes the ion field, taken to define the z-axis, plus the z-component of the electronic field in the unperturbed Hamiltonian. Perturbation theory is used for the x- and y- components of the electronic field. This leads to an inconsistency as all orders from the dressing factor associated with the z-component of the electric field are kept, but only the second order from the x and y-components. Furthermore, the convergence of this theory for the lateral Stark-split components of the line shape, though not for the central component, was taken as an indication that one could integrate down to impact parameter 0, neglecting a number of problems, such as unitarity and penetration. In particular, when penetration is taken into account, i.e., when the impact parameter becomes smaller than the atomic radial extent, it has been shown [13] that only slow collisions are strong, and fast collisions are not strong for any impact parameter. At zero impact parameter we have convergence for any velocity, while for fast enough collisions we have preservation of unitarity for all impact parameters. The reason for this convergence and unitarity preservation is penetration and not electron–ion coupling. Indeed, one obtains a convergent result even without any ions. Of course, convergence of a theory does not necessarily make it correct.