EFFECT OF PLASMA MICROFIELDS ON AUTOIONIZING STATES

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1. Introduction.

The properties of autoionizing states subjected to various physical situations have formed the basis of many recent studies. One aspect related to this general problem of particular practical importance is the phenomenon of dielectronic recombination. Here the recombination of an electron to a bound state occurs via radiative stabilization following the capture of free electrons into a Rydberg series of autoionizing resonances by the process of inverse-autoionization. The rate of dielectronic recombination is crucial for the determination of population equilibria in both astrophysical and laboratory plasmas. In fact, the topic of ionization balance in laser-pumped plasmas is of considerable current interest.

Following the work of Jacobs and Davis it has been found experimentally and confirmed theoretically that relatively weak static electric fields can cause increase in the dielectronic recombination rate up to an order of magnitude. Also LaGattuta has recently shown that similar increases can occur due to effects of an intense laser beam.

In actual plasmas, the electric fields due to the ions and electrons of
The system is subjected to impulses at a sequence of random times with

$$a_n - 1, a_{n-1}, a_{n-2}, \ldots$$

In our calculations we set $E_0 = -1$ and $H = 1$. The normalization condition is

$$H^0 = -a_0 c_0$$

In this section we present an explicitly solvable model of ionization

**II. Collisional Induced Ionization Mechanisms**

either the ionization or radiative decay rate. Characterized by the simple addition of a collison broadening width to

In the present the effects of collisional broadening cannot be safely

the dielectric relaxation time. Certainly from our studies it is clear

cause a broadening and in a manner similar to Stark fields an increase in

along with ionization decay channels. We thus infer that the dielectric fields also

ionization profile and also due to unstable mixing losses into other

ionization fields cause both an increased broadening of the direct Fano

due to a presence of a fluctuating electric field. We show that this peak

give the simultaneous results with the ionization of resonance, which is

In Section II, Following Ref. 16 we discuss a model of mixing of

production sections.

For the decay of the bound state population as well as the broadened

model can be used to describe strong isolated collisions & computed

probabilistic distribution. The strength of the impulsive is also stochastic

produces the ground state population as a result of this function

of the bound-free transitions arising by a term of this function

in Section II, Following Ref. 15 we present an exact solution to a

deformation model (production) problem

ionization through the dielectricity series rather than the inverse (le)

vortex model calculations, in which for simplicity we examine many

In order to gain insight into these phenomena, we report the results of

**I. Fundamental theory of the process of dielectronic recombination**

a fundamental theory of the process of dielectronic recombination but

indicate significant modifications of radiative opacities under astrophysical

of electron impact broadening on typical series of ionization states

is indeed sensitive to collisions In addition, the effect of the effects

and, Jacobs and Davis [14] have shown that the dielectric recombination

couple fluctuates in time By using a rate equation approach, which is
\[ H_{\text{int}} = S(t) X \]  \hspace{1cm} (2.3)

where the signal \( S(t) \) is given by

\[ S(t) = \sum_{n=0}^{\infty} \lambda_n S(t - t_n) \]  \hspace{1cm} (2.4)

and

\[ X = \int d\omega \, \tt{c}(\omega) \left| 0 \right> \left< \omega \right| + \text{h.c.} \]  \hspace{1cm} (2.5)

We restrict our attention to the Lorentzian shape continuum \( c(\omega) \)

\[ c(\omega) = \frac{1}{\pi} \frac{1}{\omega - \omega_0 - iy} \]  \hspace{1cm} (2.6)

centered at \( \omega_0 \) with width \( y \), but the methods used here can be also applied to an asymmetric Fano profile.\(^{17}\)

The driving field \( S(t) \) is assumed to be of the shot-noise type, with \( \Gamma \, dt \) as the probability for a kick to occur within a time interval \( dt \). The dead times \( T_{n-1} \) between two consecutive kicks are then independently distributed with Poissonian weight

\[ p(T_n) = \Gamma \exp(-\Gamma T_n) \]  \hspace{1cm} (2.7)

The kick strengths \( \lambda_n \) are assumed to be uncorrelated and distributed with some weight \( q(\lambda_n) \). Moreover, they are taken to be independent of the kick times. We here restrict our attention to symmetric distributions \( q(\lambda_n) = q(-\lambda_n) \), the case of asymmetric \( q(\lambda_n) \) was also considered in Ref. 15.

With the above assumptions one can explicitly solve the model for the temporal behavior of the mean population of the bound state

\[ \rho_n = \left< 0 | \hat{\rho} | 0 \right> \]  \hspace{1cm} (2.8)

and the long time mean energy spectrum of outgoing electrons:

\[ W(\omega) = \lim_{n \to \infty} \left< \omega | \hat{\rho} | \omega \right> \]  \hspace{1cm} (2.9)

In (2.8) and (2.9) \( \rho_n \) is the density operator of the system just before the \( n \)-th kick, and the bar denotes the average over the both probability distributions.

We now consider the unitary evolution operator \( U_{n,n-1} \) which transforms the density matrix from its value \( \rho_n \) just before the \( n \)-th kick to its value just before the \( (n+1) \)-th kick:

\[ \rho_{n+1} = U_{n,n-1} \rho_n U_{n,n-1}^\dagger \exp \{ i \Delta_{n-1} \} \rho_{n-1} \]  \hspace{1cm} (2.10)

Due to the impulsive character of the interaction this operator factorizes:

\[ U_{n,n-1} = \exp \{ -iT_{n-1} \} \exp \{ i \lambda_{n-1} X \} \]  \hspace{1cm} (2.11)

We can easily derive the evolution equation for the averaged density
In this section we propose a rather simple model designed to describe
the protonization process in the presence of additional fluctuating electric
fields, and obtain the spectrum of fluctuations of the protonization
rate.

![Diagram of energy vs. temperature](image)

The units of $\theta$ are deg. The dotted curve represents the shape of the continuum (at 180°).

**Fig. 1:** The long-lived section of the fluctuations versus energy measured in

$$\frac{E}{T}$$

For $\frac{E}{T} < \gamma$

$$\frac{E}{T} = \gamma$$

**Fig. 2:** The typical energy spectrum of outgoing fluctuations is shown in

where the lower limit displays the dynamical features.

\[
\begin{align*}
\left( \frac{1}{2} \right) & \left( 1 - \cos \theta \right) \\
& \left( \frac{1}{2} \right) - 1
\end{align*}
\]

The spectrum of outgoing fluctuations is given by

**Eq. 1:**

The population of the bound state decays monotonically even for high

**Eq. 2:**

In this paper we restrict our attention to a brief discussion

**Eq. 3:**

of the multilocation continuum. For the details see

**Eq. 4:**

additional dynamical equations can be solved explicitly for the locations

**Eq. 5:**

since the latter are independent of their predecessors. The resulting

**Eq. 6:**

matrix. To this end we notice that the entries of the right-hand side of

**Eq. 7:**
field such as in a plasma.

Fig. 2. Level scheme of autoionizing atom in the presence of microfield.

Our model atom (see Fig. 2) has a ground state |0⟩. Monochromatic laser light of frequency ω_0 can take it to the continuum |c⟩ or to the embedded state |1⟩. A standard configuration interaction mixes the state |1⟩ with the continuum |c⟩. It is further assumed that the dipole matrix element between the ground state and the continuum practically does not change with energy. This classical triangular configuration leads to a well-known asymmetric Fano profile. We will denote appropriate couplings as follows:

radiative: between |0⟩ and |k⟩ as Ω_k.

between |1⟩ and |l⟩ as Ω_l.

Coulombic: between |l⟩ and |k⟩ as λ.

The plasma environment is felt by the autoionizing atom as a time-dependent electric field E(t). It is a real, stochastic field. Its direction and magnitude change rapidly, but we stress that it is not an optical field. It does not have a carrier frequency.

The main effect caused by the weak microfield E(t) is dipole transitions from the embedded state |1⟩ to a set of neighboring states |l⟩ of the opposite parity. The width of the spectrum of the microfield E(t) determines the energy band around the level |1⟩ within which the coupling can be effective. Its strength is determined by the dipole moment between states |1⟩ and |l⟩, denoted by d_l. Besides, it is further assumed that each of the states |l⟩, which are not connected to the ground state, subsequently decays to the continuum through the configuration interaction. This decay is characterized by the autoionization width η_l.

The dynamical equations, derived directly from Schrödinger equation, for various amplitudes describing our model can thus be written as follows:

\[ \dot{\alpha}_0(t) = \Delta \alpha_0(t) + \Omega_0 \alpha_1(t) + \Omega_1 \beta(c, t) dc, \]
\[ \dot{\alpha}_1(t) = \Omega_0 \alpha_0(t) + E(t) \sum_i d_i \lambda \beta(c, t) dc, \]
\[ \dot{\beta}(c, t) = \eta_1 \lambda \alpha_1(t), \]
\[ \dot{\lambda}(c, t) = \alpha_0(t). \]

The amplitudes α_0, α_1, β(c) pertain to the states |0⟩, |1⟩, |l⟩, and |k⟩, respectively. The detuning Δ is a difference between the laser frequency ω_0 and
where

\[ R = \sum_{i=1}^{n} \left( \frac{1}{|i|^{2} + (\alpha + \beta)} \right) \cdot \alpha^{i} \]
\[ \delta = \text{Re} \hat{\delta}(t) \]  
(3.10) 

and

\[ \Delta^\prime = \Delta + \text{Im} \hat{\delta}(t) \]  
(3.11) 

We have introduced here standard parameters used to describe the autoionization resonance: its width \( \gamma = \lambda^2 \) and its Fano asymmetry parameter \( q = \Omega_{\gamma}/\Omega_{\lambda}{\lambda^2} \). 

2. Dense plasma.

In this case the electric microfield is a sum of many independent contributions. By invoking the central limit theorem we assume that the microfield is a real, isotropic, stationary, Gaussian process. Such a process is fully characterized by its second-order correlation function. We choose this signal to have a Lorentzian spectrum.

\[ \langle E_w(t)E_{\delta}(t') \rangle = \delta_{w,\delta} I \exp[-\Gamma |t-t'|] \]  
(3.12) 

where \( I \) is the average strength of the perturbation and \( \Gamma \) denotes the spectral width of the perturbing signal.

The explicit solution can be obtained for the case of overdamped levels \( |i, j \rangle \). If \( \gamma > \Delta^{\prime} \) and there is no backflow of population from these levels to level \( |1\rangle \), we can solve the third of equations (3.1) adiabatically and get a set of purely differential equations for \( \sigma_0 \) and \( \sigma_{1} \). The resulting formula is remarkably similar to formula (3.8):

\[ R = -2\pi q \delta \left\{ \frac{(\Delta - q\gamma)^2 + \delta^2 + \delta(\delta \gamma^2 + 1)}{\Delta^2 + (\gamma + \delta)^2} \right\} \]  
(3.13) 

Again the ionization rate shows a broadening:

\[ \delta = \frac{1}{2} \sum_{i} \frac{|d_{i}|^2}{\gamma_{i}} \]  
(3.14) 

In fact, equations (3.8) and (3.14) can both be written as the sum of two terms: \( R = S_1 + S_{\delta} \):

\[ S_1 = \frac{(\Delta - q\gamma)^2 + \delta^2}{\Delta^2 + (\gamma + \delta)^2} \]  
(3.15a) 

\[ S_{\delta} = \frac{\delta(\delta \gamma^2 + 1)}{\Delta^2 + (\gamma + \delta)^2} \]  
(3.15b) 

The first term, \( S_1 \), is the rate of direct autoionization in the presence of an incoherent loss rate \( \delta \), whereas the second term represents the loss into the decay channel. [See Eq. (4.8) of Ref. 20. Note that in Ref. 20 the decay channel loss was in the form of a photon, while in the present case, since the channels mixed in by the field can photoionize, it is an alternative route for the formation of photoelectrons.]

The broadening \( \delta \) in equation (3.8) is the Fourier transform of the electric field autocorrelation function and is essentially the electron impact width\(^19\). It is non-Markovian in the sense that \( \delta \) depends on \( \Delta \). For

References


Where our calculation approximation breaks down, the section planar fragment and decrease logarithmically in a to the point hydrodynamic (degenerate) systems (4) is consistent for a, where a is the...