A MEANLIFE MEASUREMENT OF THE $3d\,^2D$ RESONANCE DOUBLET IN SiII BY A TECHNIQUE WHICH EXACTLY ACCOUNTS FOR CASCADING

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The meanlife of the $3d\,^2D$ doublet in SiII has been determined to be 0.47 ± 0.03 ns by a technique which utilizes arbitrarily normalized decay curves of all direct cascades in the analysis of the decay curve of the measured level, and thus exactly accounts for cascade effects.

We present a description and an application of a technique for determining atomic meanlives which exactly accounts for all cascade effects. The technique requires the measurement of the intensity versus time decay curves of the level studied and all its direct cascades, but does not require a common normalization of these decay curves. A similar technique was first suggested and applied by Kohl et al. [1, 2], but required a difficult calibration of the relative detection efficiencies thoughout all of the wavelength regions which contribute direct transitions.

Consider a level of interest labeled 1, which for simplicity has only one cascade, from a level labeled 2. No restrictions are made on the multiplicity of the decay branching of either 1 or 2, nor on the degree of direct or indirect cascading into level 2. Thus the decay curves of both 1 and 2 may be highly multi-exponential in form. Assume that both decay curves are measured in some arbitrary branch (the cascade transition need not itself be measured). The particular decay branch is unimportant, since all branches must have the same shape, differing only in normalization, which will be a free parameter in our analysis. If we denote the probability of a transition from level i to level j by A_{ij}, the instantaneous level populations $N_1(t)$ and $N_2(t)$ are coupled by

$$dN_1/dt = N_2(t)A_{21} - N_1(t)/\tau_1 , \tag{1}$$

where τ_1 is the meanlife of level 1. The measured decay curves $I_{ij}(t)$ can be written in terms of $N_i(t)$, A_{ij}, and the detection efficiencies E_{ij} according to

$$I_{ij}(t) = E_{ij}N_i(t)A_{ij} . \tag{2}$$

Denoting the lower levels for the transitions from levels 1 and 2 by m and n, we use eq. (2) to rewrite eq. (1) in terms of the decay curve intensities, and obtain

$$\tau_1 dI_{1m}/dt = \xi I_{2n}(t) - I_{1m}(t) , \tag{3}$$

where $\xi \equiv \tau_1 A_{1m} A_{21} E_{1m}/A_{2n}E_{2n}$ is a normalization constant relating the two decay curves. If we integrate both sides of eq. (3) with respect to time between the limits t_I and t_F, it can be written

$$\tau_1 = a(t_I, t_F) - b(t_I, t_F)\xi , \tag{4}$$

where

$$a \equiv \int_{t_I}^{t_F} dt\, I_{1m}(t)/[I_{1m}(t_I) - I_{1m}(t_F)] , \tag{5}$$

$$b \equiv \int_{t_I}^{t_F} dt\, I_{2n}(t)/[I_{1m}(t_I) - I_{1m}(t_F)] . \tag{6}$$

Notice that τ_1 and ξ are fixed but unknown numbers, while a and b can be calculated from the measured decay curves for each choice of t_I and t_F. From eq. (4), a parametric plot of τ_1 versus ξ for various a and b gives a family of lines whose common intersection determines their simultaneous solution. Further, if all cascades are not accounted for, no such common intersection should occur, providing an internal check of completeness. This analysis can be extended to multiple cascades by adding more $b\xi$ terms to eq. (4), if the data provide sufficient constraints.

This method has been applied to a beam-foil measurement of the meanlife of the $3d\,^2D$ doublet

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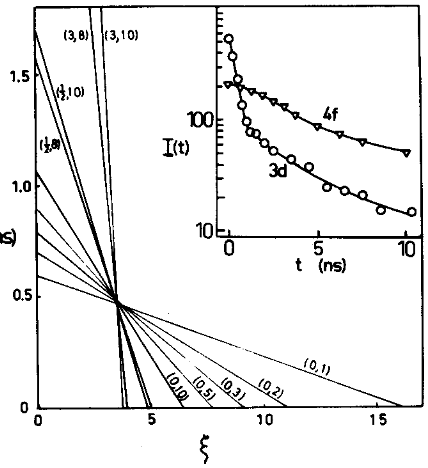

Fig. 1. Measured decay curves (inset) and parametric ξ - τ plot for data integration limits (t_I, t_F). A common intersection occurs at ξ = 3.5 and τ = 0.47.

in SiII, which has a transition often observed in Quasar absorption spectra [3]. The experimental arrangement is described elsewhere [4]. The dominant cascading into $3d^2D$ occurs from $4f^2F^o$. Other direct cascades from the higher ^2F and ^2P series were observed to be very weak. The unresolved multiplet decay curves of the $3p^2P^o$ - $3d^2D$ resonance transition at 1260 - 1265 Å and the $3d^2D$ - $4f^2F^o$ cascade transition at 4128 - 4130 Å were measured, and are shown in the inset of fig. 1. The curves were numerically integrated using a trapezoidal approximation, and a linear interpolation was made between measured data points to evaluate a and b for various values of t_I and t_F within the range $0 \leq t_I < t_F \leq 10.5$. A parametric plot of the data is shown in fig. 1. The intersection point is quite well defined (provided t_F - t_I is chosen large enough to average small statistical fluctuations) and yields a value of τ_1 = 0.47 ± 0.03 ns (the error reflects the uncertainty in the intersection). This value differs significantly from a theoretical value of 0.33 ns [5]. The intersection value of ξ = 3.5 normalizes the two decay curves, but is in arbitrary units depending upon the data accumulated. As an additional check, each of the decay curves was fitted to two exponentials, and yielded results consistent with the above technique.

This method is very promising in that it *exactly* accounts for the effects of cascades, requires no new experimental techniques, is simple to apply, and provides an internal check of its accuracy.

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