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COMMENTS AND ADDENDA

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Comment on Relative Magnetic Substate Amplitudes in Foil Excitation of Fast Hydrogen Atoms*

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If the particle-foil interaction potential governing production of H atoms coherently excited by passage through thin foils obeys the LS coupling scheme applied by Macek (conservation of z components of total orbital and spin angular momenta of the entire particle-foil system, and incoherence of final states of foil constituents), the *ad hoc* assumption that random phases prevail among the hydrogenic magnetic substate amplitudes invoked in the interpretation of certain recent experiments is avoided. Arguments concerning relative phases of states of different orbital angular momentum are unaffected.

In recent theoretical papers[1] on radiation from coherent mixtures of foil-excited atomic fine-structure states, Macek has applied a number of the results developed by Percival and Seaton in their paper[2] on polarization of atomic line radiation excited by electron impact. Among the assumptions made in Ref. 2 are first, that spin-dependent forces are totally negligible during the collision, and second, that the target has an initial state which strictly obeys the LS coupling rules. Macek's extension of the Percival-Seaton theory to the case of particle-foil interactions involves the introduction of a transition matrix element T between well-defined initial and final states of the particle-plus-entire-foil system. A further assumption that strict azimuthal symmetry about the beam (z) axis prevails (beam perpendicularly incident on a foil target assumed totally amorphous) then leads to the usual rule for conservation of the z component of total angular momentum. If spin-dependent forces are negligible during the collision and if hyperfine structure is neglected, the z components of total orbital angular momentum and of total electronic spin are separately conserved. Macek did not further specify what is meant by the "spin" or "orbital angular momentum" of the foil system, but nonetheless used these concepts[1,3] to deduce that atomic states of the emergent atom of different M_L and/or different M_S cannot interfere with one another coherently in a subsequent radiative decay process. The basic argument is that different and incoherent final magnetic substates of the foil system are paired on a one-to-one basis with magnetic substates of the emergent atom so as to conserve the total z components of the orbital and spin angular momenta. There can then be no interference among atomic states having different $M_L M_S$ designations.

It is not our purpose to comment on the validity of Macek's considerations, but merely to point out that, given their correctness, it is unnecessary to introduce an *ad hoc* assumption concerning random phases among magnetic substates of the emergent atom as was done in order to facilitate comparison between theory and certain previous experiments.[4] An apparent inconsistency in Macek's approach to the phase problem[5] is also entirely removed by appeal to the same considerations.

To be explicit, a typical interference term in the absolute squared radiative dipole matrix element contains a factor which has the structure

$A_k^* A_j e^{i\omega_{jk}t}$, where A_k and A_j are the complex amplitudes of the kth and jth eigenstates in the collision-generated atomic state, ω_{jk} is the energy difference between the kth and jth eigenstates in frequency units, and t is the time after coherent excitation.

We have omitted the radiative damping constants for simplicity. In the presence of an applied field, k and j label the perturbed eigenstates. In general, both cosine and sine terms occur; the sine terms will almost disappear in the sum over k and j if for any reason $\mathrm{Im}(A_k^* A_j)$ is small. In the previously referenced experimental work,[4] it was noted that the cosine terms were dominant. This might mean for example that the collision-generated phases of unperturbed eigenstates $|LM_LM_S\rangle$ were random, or that the relative phase factors were ± 1. If the $|LM_LM_S\rangle$ state phases were random, it was shown[6] that cosinusoidal rather than sinusoidal oscillations would occur, because the Stark mixture of eigenstates involves only real coefficients. More recent experimental Stark-effect work[7] purports to show, at least for Ly-α, that the choice ± 1 is correct.

In formulas[8] Macek has applied to the Ly-α case but under field-free circumstances, the sine terms are also missing. Cosinusoidal oscillations of light of a fixed polarization (but not of the total line intensity) still occur, driven by the spin-orbit interaction. The reason for the disappearance of the sinusoidal terms is not, as was previously thought,[5] the result of an *ad hoc* assumption about the phases of the collision-generated magnetic substates of the emergent atom; it is the consequence of the assumed properties of Macek's transition matrix T. Macek's theory still leaves open the question of coherence of different L states. The question of coherence of L-state population amplitudes is open experimentally as well.

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[1]Joseph Macek, (a) Phys. Rev. Letters 23, 1 (1969); (b) Phys. Rev. A 1, 618 (1970).

[2]I. Percival and M. Seaton, Phil. Trans. Roy. Soc. London A251, 113 (1958).

[3]Reference 1(b), p. 623; and private communication.

[4]I. A. Sellin, C. D. Moak, P. M. Griffin, and J. A. Biggerstaff, (a) Phys. Rev. 184, 56 (1969); (b) 188, 217 (1969); (c) Phys. Rev. A 1, 1553 (1970); (d) 2, 423 (1970).

[5]See the discussion in Ref. 4(d), pp. 426-7.

[6]See the discussion in Ref. 4(a), p. 61; and Ref. 4(b), p. 219.

[7]H. J. Andrä Phys. Rev. A 2, 2200 (1970).

[8]See Ref. 1(a), Eq. (4) and Ref. 1(b), Eq. (33).

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Closed-Channel Spectrum of the Positron-Hydrogen Rearrangement Collision

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For the positron-hydrogen scattering above the electron-pickup threshold, an improved upper bound on the lowest trajectory of the closed-channel Hamiltonian is obtained and its effect on the bounds on the scattering parameters is clarified.

We have reported earlier[1,2] the result of calculations of the scattering parameters for the two-channel process

$$e^+ + (e^- + p^+)_0 \to (e^+ + e^-)_0 + p^+ \qquad (1)$$

using the generalized variational-bounds (GVB) formulation.[3] Theoretical analysis of the rearrangement collisions such as (1) is complicated mainly by (a) the strong distortion effect, (b) the nonorthogonality among the open-channel wave functions, and (c) the presence of many variables describing the system. The GVB incorporate the distortion effect variationally, with resulting bounds on the scattering parameters, and treat the problem correctly by maintaining certain orthogonality properties of the operators involved, without the explicit use of the open-channel projection operator P. The number of variables involved in the problem is reduced in the GVB by an explicit construction of the effective potentials.

The statement on the bound property requires, however, *a priori* knowledge on approximate positions of some of the low-lying states of the closed-channel Hamiltonian $M_\theta(E)$, defined by

$$M_\theta(E) = M_0 + S_\theta(E) , \qquad (2)$$

where

$$M_0 \equiv H - E , \quad S_\theta(E) = M_0 G_\theta^P M_0 . \qquad (3)$$