Comments on the "Percival–Seaton Hypothesis"

It is pointed out that the extensively quoted "Percival–Seaton hypothesis" (which is based on comparison of the collision time with fine and hyperfine relaxation times) is not present in the original paper of Percival and Seaton. In addition, the concept of collision time in electron scattering experiments is discussed.

Key Words: *Percival–Seaton hypothesis, collision time, relaxation times, L-S coupling*

It is often implied in the literature (see, e.g., Gaillard *et al.*,[1] Hanne,[2] Bederson,[3b] Kazantsev *et al.*,[4] Andersen *et al.*,[5] Hippler[6]) that Percival and Seaton[7] in their seminal paper, "The Polarization of Atomic Line Radiation Excited by Electrons," *assumed* that, in the case of electron impact excitation of a light atom, if the collision time is much shorter than in the fine structure (f.s.) and the hyperfine structure (h.f.s.) relaxation times, then the total orbital angular momentum and the total spin of the electron-plus-atom system, as well as the nuclear spin, are all conserved separately. Thus, under these conditions, the collision problem can be adequately described within the LM_LSM_S coupling formalism. This assumption is usually referred to as the "Percival–Seaton hypothesis."

The purpose of this Comment is to point out that Percival and Seaton made no such hypothesis. The source of the misinterpreta-

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tion could be the statement made in the introduction of their paper (p. 115): "*The interaction* producing the collisional transition is assumed to be such that total spin and total orbital angular momenta are separately conserved."* We believe that this statement should be interpreted simply as the assumption that the electron–atom interaction term in the total Hamiltonian (essentially a sum of Coulomb interactions) commutes with the operators for total orbital angular momentum, total spin and nuclear spin. The above contention is substantiated in Sec. 3 (p. 118) where they state: "The interaction potential producing the transition is assumed not to involve spin co-ordinates." This is the mathematical formulation of the assumption mentioned in their introduction and quoted above. In the Introduction (p. 115) they further state: "If the upper level has well-defined f.s. and h.f.s., the upper states must be described in a representation in which spin and orbital angular momenta are coupled." In Sec. 3.2, they allow for weak spin-orbit coupling and in Sec. 3.3 they introduce hyperfine coupling. In the above sections, when calculating the scattering amplitudes, spin-orbit and hyperfine coupling terms are neglected in the Hamiltonian, but these effects (considered to be small) are included in the atomic wavefunction providing cross sections for the excitation of individual fine and hyperfine structure levels.

One major implication of these sections is that, in the cases under consideration (i.e., weak spin-orbit coupling and hyperfine coupling), the calculation of the scattering amplitude for the excitation of a fine structure or hyperfine structure level can always be done in two steps: (i) the complete solution of the scattering problem in the LM_LSM_S coupling formalism, followed by (ii) the construction of the scattering amplitudes via Clebsch–Gordan algebra (which is the usual perturbation approach). They do not exclude, however, the possibility that the spin-orbit coupling term has to be included in the Hamiltonian (strong spin-orbit coupling case) and that the whole scattering problem would then be solved using that Hamiltonian.

*Italics are introduced by us.

During the entire discussion in the Introduction and in Sec. 3, collision time is not mentioned. Even if it had been introduced in these sections, the "Percival–Seaton hypothesis," as it is commonly used, would be a misnomer, since these sections only review the Oppenheimer–Penney[8] (O.P.) theory of polarization.

In Section 4, where Percival and Seaton present their own theory, a certain time that we will call the "complete passage time of the wave packet," connected with the collision, is introduced. They state (p. 128): "We suppose the atom to be excited by a wave packet at time $t = 0$ and consider the wave packet to be so long that it is essentially monochromatic as far as atomic excitation processes are concerned yet so short that it can be considered to have left the atom completely at time t_1, where t_1 is small compared with the radiative life time, $1/A$ of the excited state." The essence of the two assumptions made here can be compactly summarized as:

(1) The energy spread of the wave packet is small compared to those energy splittings of the atom that are, in principle, spectroscopically resolvable (i.e., for which the energy separation of the levels is larger than the natural line widths of the levels).

(2) The time t_1 (which is so large that the scattered electron wave packet has only negligible influence on the atom for $t > t_1$) is small compared to the radiative lifetime ($\tau_{h\nu}$). This assumption allows one to treat the problem in two separate steps: collision followed by light emission.†

Percival and Seaton, in their article, considered the effect (on polarization of the emitted light) of the ratio of fine structure and hyperfine structure relaxation times (τ_{fs} and τ_{hfs}) to $\tau_{h\nu}$, but they did not compare τ_{fs} and τ_{hfs} to the collision time (τ_{coll}). However, the conventionally quoted "Percival–Seaton hypothesis" is based upon comparisons of just these times as we stated above. The ques-

†This is a fundamental assumption in the O.P. theory also.

tion then arises, who introduced for the first time this hypothesis which has been widely quoted as the "Percival–Seaton hypothesis" in the literature? The earliest publication of the mentioned hypothesis appears to be that of Rubin *et al.*[9] who state (p. 209), "It is further assumed that the collision time is sufficiently small to enable us to neglect magnetic interactions during the collision." They proceed to describe the electron collision in the LM_LSM_S coupling scheme. Subsequently, Bederson[3a] discussed the various time scales relevant to electron collision experiments and elaborated this hypothesis.

The "Percival–Seaton hypothesis" and the concept of collision time are also contained in the article of Fano and Macek.[10] Describing the emission by atoms in nonstationary states, they wrote (p. 562): "A typical collision excites the orbital motion of electrons leaving the electronic and nuclear spins unaffected." And then they state (p. 563): "The modulations which we consider result from interactions that are not only weak, but also of little relevance to the initial excitation by collision." They do not state clearly that it is because of the short duration of the collision, but it is implied. In a subsequent article Macek[11] clearly states: "The 'small' forces induce splittings of atomic levels. Transitions between split levels are characterized by a transition frequency ν or a transition period $\tau = 1/\nu$. If the period τ is large compared to the collision time (τ_{coll}), the small forces play no essential role during the collision; . . ." We can consider this statement again an independent formulation of the "Percival–Seaton hypothesis."

It is appropriate now to make a few comments on collision time in electron collision physics. Although the concept of collision time is frequently used in the literature and is appealing for the purpose of comparing it with other characteristic atomic times, it is in general a rather ill-defined quantity. This is particularly true for inelastic processes near threshold (Seaton, private communication, 1993). There has been a great deal of confusion in the literature concerning the concept of collision time. For reviews of this matter, see, e.g., Smith,[12] Goldberger and Watson,[13] Baz *et al.*,[14] Leavens and Aers,[15] Hauge and Stovneng,[16] and Sokolovski and Connor.[17] It is beyond the scope of the present Comment to address these questions. The various collision-time concepts were discussed by Hauge and Stovneng. They represent complementary information on the time aspects of the collision process. The key point here is that, in the absence of resonances, they yield a value for this time which is approximately the same as the classical passage time defined either as L/v (where L is the effective dimension of the atom or potential well representing the interaction and v is the classical velocity of the electron) or as the integrated density of electrons in the interaction region divided by the total flux of electrons through this region.[12,13,15] It is therefore understandable that in electron collision circles the classical passage time is frequently used to get an order of magnitude estimation of the collision time. In the following we are going to comment only on some collision-time concepts invoked by researchers in electron collision physics.

In a purely classical picture, $\tau_{coll} = L/v$, and all the complications associated with the electron–atom interaction are buried in L. This was presumably the approach adopted by Bederson[3] in estimating a typical value of 10^{-15} sec for the collision time in a low-energy electron scattering experiment (taking $L \approx 10$ Å and $v \approx 10^8$ cm/sec, corresponding to a 3 eV electron). This collision time is obviously different from the "complete passage time of the wave packet" discussed above.

In another scheme (applied, e.g., by Kelly,[18] Macek[11] and Hanne[2]) the collision time was obtained from the minimum uncertainty relation $\tau_{coll} = \Delta t = \hbar/\Delta E$. This procedure yields a Δt which corresponds to the time required by a wave packet of width $\Delta x \approx \hbar/\Delta p$ to pass completely a point-like atom. One may look at Δt as an upper limit for the collision time in the case of a point-like atom, but it is physically incorrect to identify it directly with collision time, because it represents only the uncertainty in time when the collision occurs, not the duration of the collision. As stated correctly by Baz *et al.*,[14] ". . . Δt here is the uncertainty at the exact collision instant. It has no relation whatsoever to the duration of collision." In the above discussion no procedure was described as to how one should assign specific values for ΔE or Δp. Hanne[2] took for the energy uncertainty, the energy resolution of the experiment, ΔE_{exp}. The problem with this approach is that it ties the collision time and, by invoking the "Percival–Seaton hypothesis," the physics of the collision to the experimental energy resolution.

In the final analysis, the "Percival–Seaton hypothesis" introduced by Rubin and Bederson[9] and Fano and Macek[10] is essentially a "sudden" or impulsive approximation. The introduction of a time-scale hierarchy (Bederson, Ref. 3) is, of course, an implicit statement about the relatively small time-integrated effects of magnetic (spin-orbit) as opposed to electric (Coulomb) forces. Analyses dependent on specific collision times, however, can be dangerous, especially when one tries to use them to make statements about the applicability of perturbation approaches to describe the collision physics or to predict the outcome of an experiment.

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