Lichten and Robatino Respond: The cause of the positron spectra[1] could be from either (1) atomic physics, (2) nuclear physics, or (3) excitation of a new particle,[1] such as the axion[2] or Higgs boson, which decays into a positron and electron. As the commenting authors note,[3] explanation (2) presents unsolved problems. (3) is speculative. We discuss their dismissal of (1) and their new calculations.

Positron formation in atomic collisions is perhaps the most difficult problem in the history of atomic physics. One reason is the unknown number of vacancies in the exit channels.[4,5] These are the vacant outer-shell orbitals which feed into the inner shells of the colliding system, in the transition region, before the systems enter the critical, "diving," extremely relativistic region. We agree that "the effects of a hole present in the $2p_{3/2}\sigma$ level would dominate the positron spectrum."[3] Other problems are the high collision velocity, which causes very strong coupling in the transition region, the further complications of relativistic interactions, and the large configuration mixing.

The authors assume that their calculations give *"an exact description of excitations of the many-particle system as long as electron correlation interactions are neglected*. . .dynamical excitations are induced by *one-body operators* $\dot{R}\,\partial/\partial R$. . ." (their italics). There are important conditions under which these assumptions are false. It was well known by early workers in the field[6–11] that the molecular orbital (MO) approximation breaks down as the atoms are separated. In the words of Coulson and Fischer, ". . .our calculation shows very clearly the dangers inherent in too naive an application of MO theory to interactions across large distances."[10]

This truth, known for half a century by chemists, is relevant to the physics of atomic collisions. Because of the breakdown of MO theory the dynamic matrix elements lose their one-electron character in the transition region between the molecular and separated-atoms domain. In systems such as U-U, U-Cm, this region occurs at internuclear separations of $R \gtrsim 0.01$ a.u. ($\gtrsim 500$ fm), just where the transitions would occur to cause the observed oscillatory phenomena. Therefore, the objections voiced in the accompanying Letter are invalid.

We give a specific counterexample of a two-electron process occurring in atomic collisions. In double K-shell excitation, in symmetric collisions, via the rotational coupling mechanism,[12] dynamic coupling between states differing by two molecular orbitals, $1s\sigma^2$ and $2p\sigma^2$, is crucial.[13–15] Within the MO approximation, there is no possible transition via one-electron jumps. Such jumps would change parity, which is conserved in electromagnetic interactions.

Until transitions among other shells, such as $2p\sigma_{1/2}$ and $2p\sigma_{3/2}$, are investigated as systematically as in the case of K shells, one cannot exclude the purely atomic mechanism of sharp positron line formation.[16]

Our simple model calculation is not rigorous enough to exclude the nonatomic explanations of the spectra. Nevertheless, scientific parsimony asks for more conclusive evidence against the atomic explanation (1), before one reaches the more dramatic conclusions (2) or (3). Most conservatively, it would be best to consider the matter open until further experiments to decide among possibilities (1), (2), and (3). An anisotropic angular distribution of positrons in the peak regions would be evidence for (1). Mechanism (2) might lead to distinctive decay products of the compound nucleus. A resonance of the e^+-e^- system at a few hundred kiloelectronvolts might be observable by a collider experiment.[2] Meanwhile, atomic theory must become more sophisticated before it can make definitive statements about the interpretations of these intriguing experiments.

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