PERSPECTIVES: ATOMIC PHYSICS

Fragmentation Processes in Atomic Collisions

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Atomic scattering experiments have a long and illustrious history, dating back to Rutherford's early experiments. However, the detailed description of collision processes involving more than two charged particles has long presented a serious challenge to theory and experiment alike. Revolutionary advances in experimental techniques and spectacular increases in computer power now offer an opportunity to develop a much more profound understanding of the atomic few-body problem. One of the simplest examples, the ionization of atomic hydrogen by an impacting electron, has been extensively studied in (e, 2e) experiments. The detailed experimental data now available provide a benchmark against which to judge the value of different theoretical approaches to this paradigm of Coulomb three-body problems. On page 2474 of this issue, Rescigno *et al.* (*1*) present an important new computational approach that gives excellent agreement with the best available experimental data.

In their research article, Rescigno *et al.* consider the ionization of hydrogen at energies just above threshold. In this regime, Ehrhardt and his collaborators (*2*, *3*) have performed a series of precise, absolute measurements in a range of geometries. A qualitative picture of the basic physics was provided in (*4*), where it was shown that the shape of the experimentally measured cross section (*5*) was the result of a delicate interplay between three-body effects in the incident channel (such as polarization of the target by the projectile) and postcollisional Coulombic interactions between the three free particles in the final state.

The final state interaction has a geometric character, the observed cross section being sensitive to where the electrons are detected, and the speed at which they are moving. In coplanar symmetric geometry, both electrons are detected with equal energies, at equal angles right and left of the beam direction; this causes problems at low energies because incident and final channel effects interfere. In contrast, in a fixed ϑ_{12} geometry,

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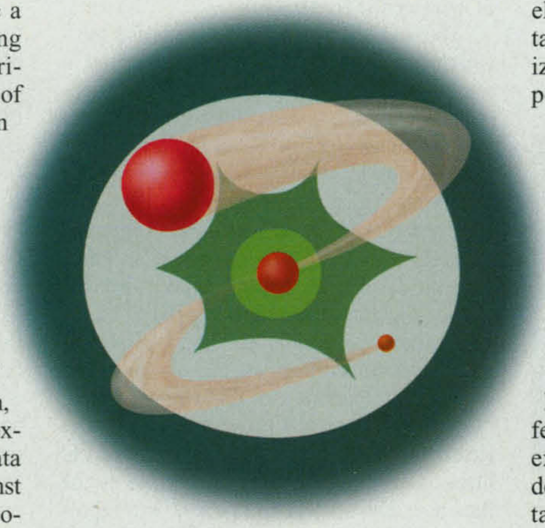

Symbolic representation of an (e, 2e) process.

the electrons are detected such that their mutual angle, ϑ_{12}, is always held constant. In this case, the shape of the cross section largely depends on incident channel effects, although its absolute size continues to be influenced by the final state Coulombic interactions (*6*). This was the motivation for the experiments described in (*3*): By holding ϑ_{12} constant, the effect of the interactions in the incident channel could be isolated, providing a testing ground for theory.

One particularly fruitful theoretical approach to the problem used a coupled pseudostate approach where the full solution of the Schrödinger equation is approximated by a finite basis expansion. This approach was pioneered by Curran and Walters (*7*) and is the basis of the convergent close coupling method (*8*). The latter gives very good agreement with experiment over a wide range of kinematics and energies. The shape of the cross section can be reproduced closely, but the theory has real difficulty in predicting its absolute size, especially when the exiting electrons have equal or near equal energies. My own view is that this failing is largely a result of the asymmetric way that the approximation was set up, that is the way the cross section is extracted from the wave function rather than the close-coupling wave function itself. Rescigno *et al.* (*1*) present a more symmetric approach and obtain good results for the absolute size and the shape of the cross section for both coplanar symmetric and constant ϑ_{12} geometries.

Where do we go from here? (e, 2e) experiments have long moved on from hydrogen to study other atoms, as well as molecules and solids; recently, we have seen the first results on surfaces (*9*). One area of critical focus in the next few years will be on processes with two active target electrons (such as double ionization, excitation ionization, and excitation autoionization), where the cross sections will depend on target correlation, final state interactions between the ejected electrons and higher order interactions with the incident/scattered particle (*10*). Recent complete double ionization measurements with ionic projectiles (*11*) may be complemented by measurements with photons, electrons, and ions in different charge states. These will surely be focused, at the least initially, on two active target electron problems. Fascinating insights into relativistic effects have also been unearthed by (e, 2e) experiments at very high energies. The deep inner shell ionization of heavy metal targets by relativistic electrons has been studied (*12*), and the effects of Mott scattering, Pauli blocking, spin-flip, multiple scattering, retardation, and magnetic effects have been measured.

The range and variety of these fast-evolving experimental techniques present a formidable challenge to theory. The kinematics and geometries presently accessible to measurement are so numerous, the targets and projectiles so varied, and the cross section so small and delicate, that theory must not only respond to measurements but also take a role in guiding the ongoing experimental program. Much remains to be done but at least a start has been made.

References and Notes

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3. J. Röder *et al.*, *Phys. Rev. A* **53**, 225 (1996).
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5. An (e, 2e) experiment measures the triple differential cross section, that is, the number of events corresponding to two final state electrons detected at fixed position in space with well-defined energies per unit time per unit scatterer as compared with the incident flux.
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References and Notes

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