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The angular distribution of 5-eV electrons ejected from hydrogen atoms by the impact of keV protons that are themselvesscattered through 0. The peak near 30"from the forward direction is the binary peak; that near " is the recoil peak. However, for large scattering angles it is obviously the nucleus-nucleus interaction that plays the dominant role. The effect of this interaction on the structure of differential cross sections for ionization will now be considered. The major effect of the projectile-electron interaction is well known and leads to striking structure in the differential cross section whenever k z vp, the projectile velocity in the laboratory frame. A similar analysis as led to Eq. When integrated over a small finite region of k space as for the finite resolution and acceptance angle of a detector this singular factor gives rise to the well-known cusplike structures in differential cross sections for positive-ion impact Crooks and Rudd, , ; Lucas and Harrison, ; Lucas et al. An example is shown in Fig. Macek A similar normalization factor occurs in the case of negative proton impact. Such a dip structure in the differential cross section for impact ionization by negative protons has been predicted by Garibotti and Miraglia The real parameters fir. The variation with k is contained in the state multipoles via their connection with density-matrix elements and scattering amplitudes given by Eqs. The simplicity of the first Born amplitude for direct ionization and, in particular, its symmetry properties allow certain general statements to be made as to the angular distributions for example, those shown in Fig. Clearly this is a very strong criterion with which to check the applicability of the first Born approximation. Hence the first Born approximation permits no sp, sf, pd, etc. As discussed by Scholler et al. Hence the BL provide the link between the shapes of excited states and the angular distribution in the continuum. The preceding considerations are based on a description of continuum electrons with Irn quantum numbers referred to the target nucleus as origin. An entirely analogous form can be written in terms of angles of emission with respect to a frame fixed in the projectile. Then the cross section, differential in k, the electron momentum in the projectile frame, can be written where now the coefficients PL are defined by Eq. Clearly in the limit that the electron has low momentum with respect to either target or projectile nucleus, where the three-body continuum approximates more nearly to a two-body one, Eq. Indeed, since it is difficult to measure low-energy electrons in the target laboratory frame, most discussion of angular distributions as of early has been in terms of Eq. This description of continuum angular distribution is appropriate to describe ionization of 28 J. Macek electrons into low-momentum projectile states, as in the case of electron loss to the continuum ELC where the electron is initially bound to the projectile, or in the case of ECC, where the electron originates from the target. That the angular distribution of cusp-continuum electrons should extrapolate smoothly below the projectile threshold to connect with the coherent excitation of ELC , or capture into ECC , Rydberg states has been emphasized particularly by Burgdorfer He also provided an analysis of the symmetry properties of the PL coefficients that has proved extremely useful in assessing the extent to which first Born or higher-order theories are capable of describing particular aspects of coherence or angular-distribution asymmetry. Two aspects of the symmetries of the problem are important: This latter symmetry results in the well-known presence of an additional constant of the motion, the Runge-Lenz vector, for two-body Coulomb states. Burgdorfer expresses the anisotropy parameters for bound states in terms of expectation values of O 4 group generators i. This is to be contrasted with the approach based on O 3 group generators angular momentum I in which the parameters PL appear as an infinite sum of multipoles. Hence, although all 1 partial waves contribute at the threshold, the following selection rules can be proved for the threshold PL in first Born approximation either for ionization or capture. This is a consequence of the parity and time-reversal properties of the first Born matrix elements. For capture only Po is nonzero. This can be seen from Eqs. These features are a consequence of the O 4 symmetry of the Coulomb force. One sees that anisotropy and, in particular, forward-backward asymmetry are very sensitive tests of the validity of firstorder theories. We shall return to the point when discussing higher-order theories. The foregoing has referred to initial 1s states, where any anisotropy in angular distributions is a direct result of collision dynamics. For nonisotropic initial states, the low-lying-continuum angular distribution is a complicated mixture of effects of initial anisotropy and collision-induced anisotropy. For example, Burgdorfer has generalized the preceding selection rule b to show that in PWBA the angular distribution for ionization from an initial state nlm has nonzero Br. The coefficients themselves depend strongly on nlm and the projectile velocity. In addition, it has often been emphasized that in the case of cusp electrons, the measured electron distribution depends crucially upon the acceptance aperture of the detector. This is because the calculated cross section is singular and the integral over this singularity depends sensitively on the limits of integration. Such structures have only been studied in first Born theories as of early These features are a peaks due to a single binary collision between projectile and target electron, b peaks due to recoil of slow electrons from the target nucleus, and c peaks due to the strongly enhanced density of states normalization factor for approximate two-body states corresponding to final-state interaction between electrons moving slowly relative to either target or projectile nucleus. It will now be shown that higher-order processes lead to new structures or seriously alter the shape momentum distribution of structures 30 J. Macek already present in the first Born lowest-order description of ionization. The new structures are due to sequences of double binary collisions, obviously arising first of all in the second Born approximation. Since capture to the continuum cannot occur in a single binary collision, it emerges that such higher-order processes have a strong effect on the shape of electronmomentum distributions for ECC processes. Indeed, one sees that, taken in its entirety, the process of ionization can never be considered as a first-order process. Only that part involving very small momentum transfer approximates at all the first Born description. Any large momentum transfer, either to the electron or to the target nucleus, has nonnegligible contributions from highqr-order multiple-scattering collisions. Such multiple-scattering collisions are the subject of this section. Scattering through angles much larger than this requires the nucleus-nucleus potential. One can then ask what happens if the incoming nucleus also scatters off the electron, either before or after the scattering off the target nucleus? As with the PWBA, Eqs 71 and 7 9 , the structure of binary collisions can be analyzed by considering that all propagation during and after the collisions is in plane waves.

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As a result, he believed that electrons revolved around the proton. Niels Bohr , in , combined the Rutherford model of the atom with the quantisation ideas of Planck. Only specific and well-defined orbits of the electron could exist, which also do not radiate light. In jumping orbit the electron would emit or absorb light corresponding to the difference in energy of the orbits. His prediction of the energy levels was then consistent with observation. In Einstein created an extension to Bohrs model by the introduction of the three processes of stimulated emission , spontaneous emission and absorption electromagnetic radiation. Which aspects of the problem are treated quantum mechanically and which are treated classically is dependent on the specific problem at hand. The semi-classical approach is ubiquitous in computational work within AMO, largely due to the large decrease in computational cost and complexity associated with it. For matter under the action of a laser, a fully quantum mechanical treatment of the atomic or molecular system is combined with the system being under the action of a classical electromagnetic field. In low speed collisions the approximation fails. Atomic models will consist of a single nucleus that may be surrounded by one or more bound electrons, whilst molecular models are typically concerned with molecular hydrogen and its molecular hydrogen ion. It is concerned with processes such as ionization , above threshold ionization and excitation by photons or collisions with atomic particles. While modelling atoms in isolation may not seem realistic, if one considers molecules in a gas or plasma then the time-scales for molecule-molecule interactions are huge in comparison to the atomic and molecular processes that we are concerned with. This means that the individual molecules can be treated as if each were in isolation for the vast majority of the time. By this consideration atomic and molecular physics provides the underlying theory in plasma physics and atmospheric physics even though both deal with huge numbers of molecules. Electronic configuration[edit] Electrons form notional shells around the nucleus. These are naturally in a ground state but can be excited by the absorption of energy from light photons , magnetic fields, or interaction with a colliding particle typically other electrons. Electrons that populate a shell are said to be in a bound state. The energy necessary to remove an electron from its shell taking it to infinity is called the binding energy. Any quantity of energy absorbed by the electron in excess of this amount is converted to kinetic energy according to the conservation of energy. The atom is said to have undergone the process of ionization. In the event that the electron absorbs a quantity of energy less than the binding energy, it may transition to an excited state or to a virtual state. After a statistically sufficient quantity of time, an electron in an excited state will undergo a transition to a lower state via spontaneous emission. The change in energy between the two energy levels must be accounted for conservation of energy. In a neutral atom, the system will emit a photon of the difference in energy. However, if the lower state is in an inner shell, a phenomenon known as the Auger effect may take place where the energy is transferred to another bound electrons causing it to go into the continuum. This allows one to multiply ionize an atom with a single photon. There are strict selection rules as to the electronic configurations that can be reached by excitation by lightâ€”however there are no such rules for excitation by collision processes.

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