Analytical formulas for differential cross sections for ejection of electrons in ionization of water by protons in the PWBA and ECPSSR

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Analytical formulas for differential cross sections for ejection of electrons in ionization of water by protons in the PWBA and ECPSSR

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Synopsis. For comparison with measured ionization cross sections as a function of the ejected electrons from water by protons, analytical formulas of the plane-wave Born approximation (PWBA) and the ECPSSR theory -- that accounting for the energy-loss (E) and Coulomb-deflection (C) protons and perturbed-stationary states (PSS) and relativistic (R) of electrons goes beyond the PWBA -- are evaluated analytically. As opposed to the PWBA that overestimates the data with the increasing energy of the ejected electrons, the ECPSSR is in good agreement with the measured spectra of the electrons ejected in with keV to MeV energies.

Single-differential cross sections (SDSC) with respect to the energy transfer in production of secondary electrons are required in detailed modeling of interaction of ionizing radiation with matter; in particular, in proton bombardment of biological materials of which water is a prime constituent. The existing SDCS calculations are typically developed in the first Born approach (FBA) of the plane-wave Born approximation (PWBA), done with semi-empirical corrections for the breakdown of the FBA with the decreasing proton energy and performed numerically [1,2].

Our analytical PWBA formulas based both on atomic and molecular composition of water are comprehensively compared with SDCS for electron ejection measured in ionization of water vapor by 0.15-4.2 MeV protons [3]. Analytical corrections of the ECPSSR theory [4] that goes beyond the FBA do not remove existing discrepancies with data obtained with slow protons and for the slowly ejected electrons. Predictions of the theory, however, are shown to result in increasingly smaller cross sections with the increasing energy of the ejected electrons and increasingly so in ionization by just a few hundred keV-protons. This could be a significant change as an input for Monte Carlo track structure codes in water and other biologically relevant materials.

As measurements with ice in conjunction with vapor data may support a bridge over troubled liquid water, new ideas that impose limitations on the range of momentum transfer in the derived analytical formulas for solid-state water will be discussed.

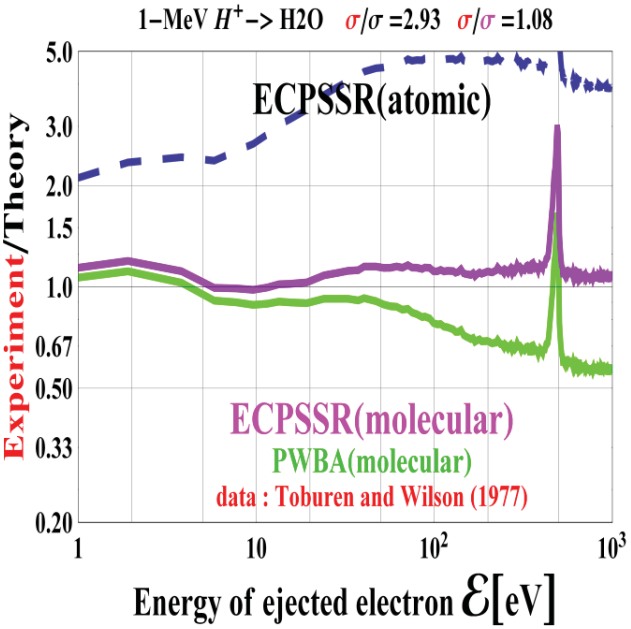

Fig.1. Ratios of experimental spectrum for SDSC in ionization of water vapor by 1-MeV protons [3] to the results of the plane-wave Born approximation [1,2] and the ECPSSR theory using atomic and molecular states for water [4].

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