QUANTUM VORTICES IN THE THREE-BODY CONTINUUM INDUCED BY THE POSITRON-IMPACT IONIZATION OF HYDROGEN

F. Navarrete, J. Fiol, R. O. Barrachina

Centro Atómico Bariloche and Instituto Balseiro (Comisión Nacional de Energía Atómica, CNEA, and Universidad Nacional de Cuyo, UNC), R8402AGP S. C. de Bariloche, Río Negro, Argentina.

Vortices are very well-known features of many-body systems. They are routinely observed in gases, liquids and plasmas, and in connection with quantum effects as superfluidity, superconductivity, and Bose-Einstein condensation. The description of these many body systems customarily resorts to the inclusion of ad-hoc potentials or nonlinear terms. Here, on the other hand, we investigate their appearance in an extremely simple quantum system, consisting of an electron, a positron and a proton. The origin and evolution of the vortices in this three-body system are governed by their Coulomb interactions via the Schrödinger equation.

We investigate the ionization of atomic hydrogen by the impact of positrons. The time evolution of the corresponding electron - positron - proton system is equivalent to the flow of a perfect fluid that is irrotational everywhere [1,2], except at vortices where the corresponding density vanishes. During the ionization process, vortices emerge as closed submanifolds or in pairs of opposite circulation [3]. They may collapse at later times, but some can survive up to macroscopic distances and, according to the imaging theorem [4], manifest themselves as zeros of the ionization matrix element T [5]. We have recently conducted for the first time a search for vortices in the transition matrix element T for the positron-impact ionization of hydrogen [6]. These quantum structures had been previously investigated in the ionization of atoms by the impact of electrons [5], and ions [7], and by intense electric pulses [8], but not by positrons.

A significant difficulty on the description of the vortices is the large number of variables on which the T-matrix depends. The rotational symmetry about the axis of the collision, together with the conservation of energy and momentum, reduces the number of relevant scalar variables from nine to four. Still, a further reduction of the dimensionality is compulsory in order to reach a visualization of T. As it is the case in all other studies of vortices in ionization processes conducted so far, we rely on a geometry that projects T onto a two-dimensional plane. Instead of the "symmetric geometry" [9] customarily used in the study of (e,2e) collisions, we employ an "energy sharing" or collinear arrangement, where the electron and the positron move along the same direction in the final state. Since any vortex would span a submanifold of codimension 2 in the 4D space of the independent scalar variables of T [3], it would show up as an isolated zero in a collinear arrangement.

The first theoretical evidence of the presence of a vortex in the ionization of atoms by positron impact, even though at that time it was not recognized as a vortex itself, was provided by Brauner and Briggs [10], who in 1991 found a deep minimum of about three orders of magnitude in the corresponding differential cross section. Unfortunately, the extremely large impact energies between 10 and 100 keV where this effect was observed, might have discouraged any attempt to measure it. More recently, we observed the presence of another minimum which was not related to the previous one [11]. We again failed to recognize it as a vortex, but showed that it persists at impact energies as small as 30 eV, thus being amenable to experimental investigation.

Here we perform a systematic study of vortices in the $e^+ + H$ ionization collision. We evaluate the transition matrix element T by employing a correlated C3 approximation of the final three-body state [12] whose main characteristics are described in previous articles (see e.g. [6]). We demonstrate that the minima found by Brauner and Briggs [10] and Della Picca et al. [11] in the differential cross section, actually represent vortices, i.e. they are zeros of the real and the imaginary parts of the transition-matrix with a circulation equal to 2π around each of them [3]. We show that Brauner and Briggs' vortex still persists at energies of the order of 250 eV, so as to make its experimental observation feasible. Finally, since vortices emerge either as closed submanifolds or in pairs of opposite circulation [3], we search for the companions of these two vortices, investigate at which impact energy they separate, and their characteristics and locations in momentum space.

Let us finally mention that the vortices studied in this communication occur at impact energies that make feasible its experimental observation. Furthermore we discuss how the study of their circulation might be at reach by means of weak pre- and post-selected measurements. On the theoretical side, we explore the full vortex submanifold beyond the cut of minimum dimensionality imposed by the collinear geometry, a study which represents the next obvious step in the quest for understanding the topology and dynamics of these fascinating few-body quantum structures.

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E-mail: barra@cab.cnea.gov.ar