ATOMIC REALIZATION OF THE YOUNG SINGLE ELECTRON INTERFERENCE PROCESS IN INDIVIDUAL AUTOIONIZATION COLLISIONS

R. O. BARRACHINA*
Centro Atómico Bariloche and Instituto Balseiro,†
8400 S. C. de Bariloche, Río Negro, Argentina.
E-mail: barrachina@ib.edu.ar

M. ŽITNIK
J. Stefan Institute,
Jamova 39, P. O. Box 3000,
SI 1000 Ljubljana, Slovenia.
E-mail: Matjaz.Zitnik@ijs.si

Young's double-slit demonstration, applied to the interference of single electrons, is considered to be one of the most beautiful experiments in Physics. This "gedanken" experiment proposed by R. Feynman in 1963, was achieved quite recently. Of course, the diffraction of electrons by atomic arrays had already been studied many decades before, but the novelty in these experiments was that one electron at a time collides with a single two-slit arrangement. Here we propose a novel atomic realization of a Young interference experiment, where a single electron source and a two-center scatterer are prepared in each collision event.

1. Historical Introduction

Even though the concept of interference was already implicit in Newton's 1688 explanation of the anomaly of the tides in the Gulf of Tongkin, it was Thomas Young in his Bakerian Lectures of 1801 who generalized this idea and applied it to a variety of situations. His celebrated double-slit experiment, first described in his Course of Lectures on Natural Philosophy and the Mechanical Arts of 1807[1], has been regarded as a prime demonstration

*Also a member of the Consejo Nacional de Investigaciones Científicas y Técnicas (CONICET), Argentina.
†Comisión Nacional de Energía Atómica (CNEA) and Universidad Nacional de Cuyo, Argentina.

of the wave-nature of light and, in its single electron interference version, was recently voted as the most beautiful experiment in Physics[2].

Young's double-slit demonstration applied to the interference of single particles was proposed by Richard Feynman in his famous lectures of 1963[3] as a "gedanken" experiment. But he warned that nobody should try to set this experiment up. He added that "the trouble is that the apparatus would have to be made on an impossibly small scale to show the effects we are interested in". Contrary to this assertion, we demonstrate the viability of such an atomic size apparatus.

Probably Feynman was not aware that a double-slit experiment with electrons had already been carried out in 1961 by Claus Jönsson[4]; and this was certainly not the first experiment where electron interference was observed. The first experiment to demonstrate electron interference by molecules had been performed by R. Wierl in 1931[5], shortly after the Nobel-prized electron diffraction experiment by Davisson and Germer[6]. The very short wavelength of electrons were afterwards exploited to study molecular structures and for surface crystallography. Particle interference has also been demonstrated with neutrons, atoms and molecules. However, none of these experiments was designed to demonstrate that an interference pattern would build up even if there is just one electron in the apparatus at any one time, i.e. that "each electron interferes only with itself". This was achieved only in the 1970s with a very weak electron source and an electron biprism by Merli et al.[7] and again by Tonomura et al. in the late eighties[8].

2. An atomic scale setup

One of the major difficulties in the design of single-electron double-slit experiments is to prevent any chance of finding two or more electrons in the apparatus at the same time. Merli et al. and Tonomura et al. achieved this goal by carrying the experiment with extremely low electron intensities. Our proposal is to fulfill this same exigency in a simple and natural way by destroying the apparatus after each single-electron interference event.

This idea is not so wild as it might sound, since we are not referring to a macroscopic experimental setup but to atomic-size "apparatuses" inside it. Instead of sending a beam of electrons against some sort of two-slit arrangements, a single electron source and a two-center scatterer are prepared in individual atomic collisions. These different events only amount to repeating an elementary process many times with similar initial conditions. Thus, what is actually measured is the *ensemble* probability of the diffraction of just one *single* electron by one *single* two-center scatterer[9].

As the electron source of this atomic-level laboratory arrangement we propose to employ the spontaneous electron emission with a sharply defined energy and a characteristic angular distribution from an autoionizing atom. A diatomic molecule, taking part in the collision event that leads to the formation of the autoinizing atom, might serve as the atomic-size two-slits arrangement.

Note that in this setup the source and the two-center scatterer are well defined and separated. This pinpoints to an essential difference with the interference effects observed by Stolterfoht et al. [10] in the ionization of H_2 molecules by energetic ion impact. In this latter case the electron is not coming from a distinct source but from the two-center scatterer itself so that it is much more related to a x-ray-photoelectron or Auger-electron diffraction (XPD/AED) effect than to the famous Young's demonstration.

One of the main achievements in the Merli and Tonomura experiments was that the formation of fringes could be observed over time as the electrons were gradually accumulating. In our case, this same result might be achieved by means of standard electron-spectrometry techniques, where the electrons arrive randomly to the detector, so that it would take some time for the interference pattern to build-up.

As an example of the aforementioned atomic realization of the Young single-electron interference process we consider the $(2s^2)^1S$ autoionization of He^{**} induced by a $\mathrm{He}^{2+} + \mathrm{H}_2$ double electron capture collision. It is assumed that the molecule dissociates after the collision. We show in figure 1 a Continuum Distorted Wave (CDW) calculation of this process[9]. We see that, together with a glory enhancement of the autoionization line, the normalized electron distribution shows a noticeable interference structure. This structure is partially washed out when it is averaged on the molecule orientation.

3. Conclusions

Up to our best knowledge, the experiment described in this communication has not yet been performed. It will be certainly hindered by a number of difficulties. But, they would not be too much different than those encountered by Swenson et al.[11] in their beautiful observation of the Glory effect in a $\mathrm{He}^{+} + \mathrm{He}$ collision. As a reward, Feynman's famous double-slit Gedanken experiment might be observed and registered in real time and under the required single-electron conditions.

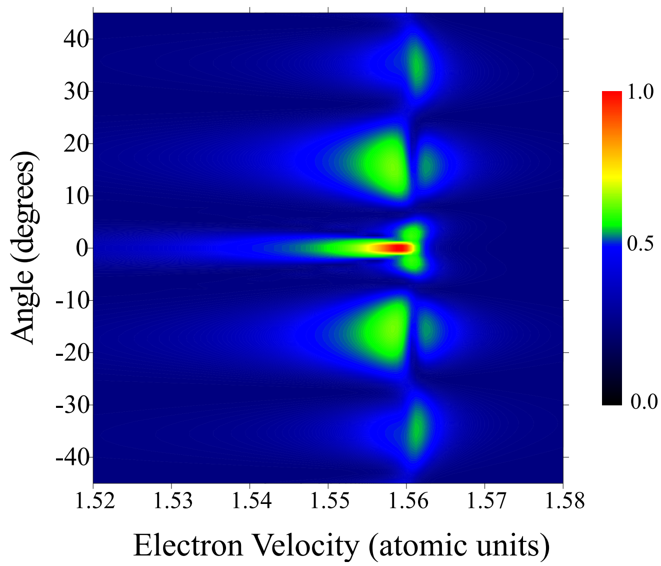

Figure 1. Normalized electron intensity as a function of the emission angle and velocity for the $(2s^2)^1S$ autoionization of He^{**} induced by a 100 keV $\mathrm{He}^{2+} + \mathrm{H}_2$ double electron capture collision. The results are shown in the coordinate frame of the He atom. The dissociation of the H_2 occurs in a direction perpendicular to the projectile's trajectory.

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