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Observing Quantum Level Interference Effects with Electron Spectrometer

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The existence of Young-type interference patterns has been recently searched in triple differential cross-sections for single ionization of H_2 molecules by electron impact, and theoretically supported by calculations obtained by different models. The appearance of interference effects arising from the two-centre geometry of diatomic molecule. These effects seen in triple differential cross-sections are described by interference factor in analogy with light waves. In this work, we discuss about that the interference factor for molecular structure of H_2 may reproduce Young-type interference patterns depending on scattering angle, initial and ejected electron energies in triple differential cross--sections. Differences are expected in the triple differential cross-sections spectra of ejected electrons according to kinematical conditions imposed by scattering angle and electron energy.

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1. Introduction

The admittance of wave-particle duality is considered as a milestone in the development of quantum mechanics. The experiment on this is done more than two centuries ago by Thomas Young by measuring the interference pattern behind a double slit. Nowadays, the innovative concepts of Young double slit interference effects are investigated in the ionization cross-sections of diatomic molecules such as H_2 and N_2 by electron or ion impact. The idea of interference in collisions of diatomic molecules by electrons was first discussed by Cohen and Fano et al. [1] and the first experimental evidence of interference effects in single ionization of molecules by ion impact was measured by Stolterfoht et al. [2]. Later on Stia et al. [3], suggested in their theoretical calculations that interference effects are expected to be seen in the electron impact ionization cross-section so called TDCS spectra of H_2. In this context, Stia et al. [3] emphasized that the interference effects should be observable in the triple differential cross-sections (TDCS) of H_2 molecule by electron impact. As a result of this study, interference effects looked forward to as probable in coplanar asymmetric kinematics where incident, scattered and ejected electrons belong to the same plane. Since then, experimentalists have studied on electron impact ionization cross-sections of the basic molecule H_2 for several years [4–8]. TDCS measurements are recently done by two groups to search the observability of interference effects in asymmetric kinematics [4, 5]. Motivated by these measurements, we have searched the behavior of interference effects depending on ejected electron energy and scattering electron angle.

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2. Experimental setup

We have measured the TDCSs, for electron impact ionization of He and H_2 molecules in the intermediate-energy region using a newly developed crossed-beam-type electron–electron coincidence spectrometer in Afyon, Turkey. The construction of the spectrometer for the study of relative TDCS measurements for electron impact ionization has been completed in our laboratory. Further explanations of the similar setup used for the same type experiments are to be found in Refs [9] and [10]. The electron spectrometer consists of an electron gun, two hemispherical electrostatic analyzers, a Faraday cup, gas line and electronic control units for data acquisition. The electron beam crosses by the target gas at the interaction region in the perpendicular plane. The scattered and ejected electrons are detected by electron energy analyzers after the collision.

3. Results and discussion

The Young double slit interferences may lead to oscillations and associated interference leaves their sign in the TDCS spectra of electron impact ionization of H_2 molecule. The oscillations seen in the TDCS spectra are explained by interference factor (I) by Stia's theoretical model [3]:

$$I = 1 + \frac{\sin(Q\rho_0)}{Q\rho_0}. \quad (1)$$

In Eq. (1), $Q = k_0 - k_a - k_b$ is the momentum transferred to the residual (recoil) ion. k_0, k_a and k_b are the momentum of the incident, scattered and ejected electrons, respectively in the formula of Q and ρ_0 is the equilibrium internuclear distance in the target molecule that is 1.4 a.u. for H_2. Concisely, the interference factor depends on the ejected electron momentum, the momentum transferred by the projectile to electron and the internuclear distance of the scattering centers. In this model [3], TDCS distribution for molecular hydrogen can be modeled as twice TDCS distribution of the atomic hydrogen.

The difference with the case of interest in this work resides in the fact that interference factor changes depending on ejected electron energy and scattering electron angle. Figure 1a,b shows the interference factor upon scattering electron angle for 20 and 50 eV fixed ejection electron energies. Figure 1c,d shows the interference factor upon on ejected electron energy for several fixed scattering electron energies at 250 eV initial electron energy.

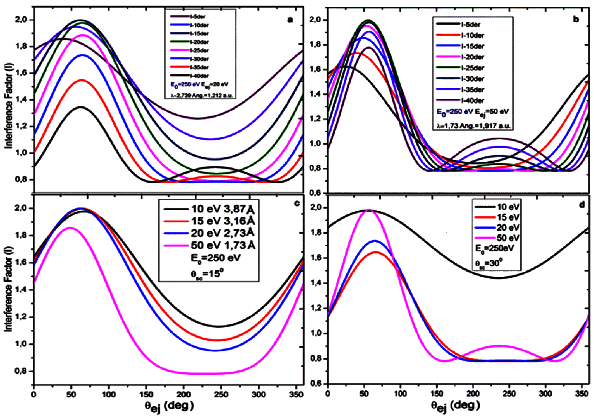

Fig. 1. Interference effect depending on scattering angle for 20 eV (a) and 50 eV (b) ejected electron energies plotted as ejected electron angle. Interference effect for 15° (c) and 30° (d) degree scattering electron angles for 10, 15, 20 and 50 eV ejected electron energy plotted as ejected electron angle.

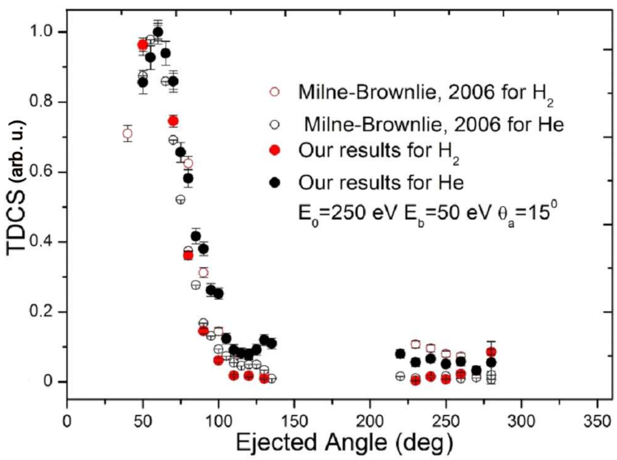

Fig. 2. TDCS results for 50 eV ejected electron energy and 15 degree scattering angle for He and H_2 molecule under the same kinematics.

From Fig. 1 it can be seen that at high enough impact energies and asymmetric energy conditions, the interference factor difference depends on scattering angle more dominantly than ejected electron energy distribution. This effect might be expected to see in TDCS results as changes in the recoil peak intensity relative to the binary peak such as constructive and destructive interferences.

In this work we have measured the TDCS spectra of electron impact ionization of He and H_2 at 50 eV ejected electron energy and 15 degree scattering angle. Figure 2 shows the current results in comparison with Milne--Brownlie et al. [4]. TDCS results for both targets at the same kinematics.

Milne-Brownlie et al. have reported the possibility of the observation of destructive interference effects in TDCS results for H_2 for 250 eV incident electron energy and 50 eV ejected electron energy at 15 degree of scattering angle. Since the results for both targets are pretty similar to Milne-Brownlie et al., we concluded that our spectrometer supports these data and works in a consistent way.

The discussion of the behavior of interference factor in terms of molecular two center interference is a highlight for (e, 2e) studies in this field. The further measurements for observing possible interference effects are being made in this newly developed experimental apparatus.

Acknowledgments

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