Turk J Phys
26 (2002) , 219 – 224.

The Electron-Photon Coincidence Method and its Application to Excitation of the 2P State of Atomic Hydrogen

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Received 10.11.2000

Abstract

Early measurements of atomic excitation by electron scattering observed either the scattered electron or decay photon. An excited state can not be completely defined by such experiments due to loss of information. Therefore a new method was developed in the early 70's called the correlation method.

The new correlation method involves the detection of both the scattered electron and photon arising from the same collision using coincidence techniques.

This method enables a full description of an excited state. In this paper, we give a discussion of to the method and its application to excitation of the 2p state of atomic hydrogen.

Key Words: Angular Correlation, Electron-Photon Coincidence, Excitation, Electron Scattering.

1. Introduction

The electron-atom excitation process has been widely studied both theoretically and experimentally (see reviews of Blum and Kleinpoppen [1], Slevin [2], Andersen et al. [3], Slevin and Chwirot [4], Becker et al. [5], Crowe [6] and Andersen and Barschat [7]).

A typical electron impact excitation process is schematically illustrated in Figure 1 with respect to the collision frame in which the quantization axis $\boldsymbol{z}$ is taken in the incident beam direction.

This can be shown for any atom by the following general expression:

$$\begin{array}{rl} e_i(k_{in}) + A \rightarrow & A^* + e_s(k_{out}) \\ & \downarrow \\ & A + \text{ Photon} \end{array}$$

An incident beam of electrons with an angular momentum vector k_{in} is focussed onto the interaction region in the z-direction of the collision frame. These incident electrons excite the ground state atoms A to upper states A^* and scatter into some scattering angle θ_e. The excited states decay back to a lower state by emitting radiation, namely a photon, into some angle θ_γ.

A differential cross section can be obtained for a particular state at a particular electron energy, when a measurement carried out by detecting the scattered electrons with respect to the scattering angles. On the other hand, one can carry out total cross section measurements by detecting the decay photons with respect to the incident energy. These types of measurements are illustrated in Figures 2 and 3, respectively.

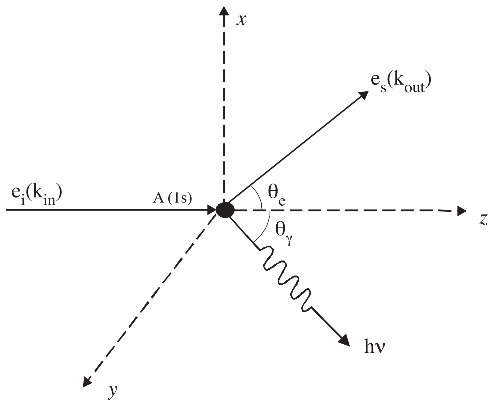

Figure 1. Schematic illustration of typical electron-atom excitation process.

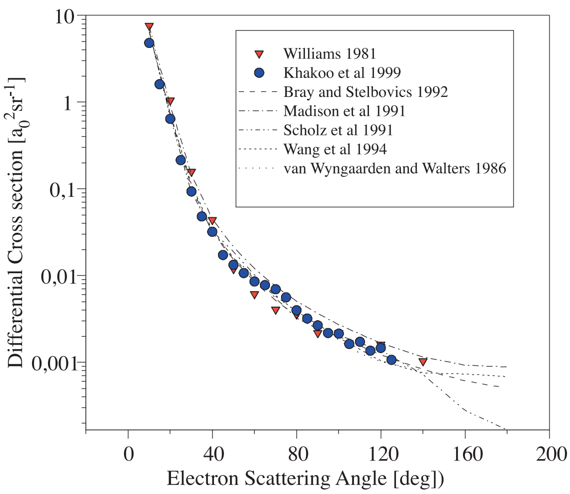

Figure 2. Differential cross section for n=2 states of atomic hydrogen at 54.4eV.

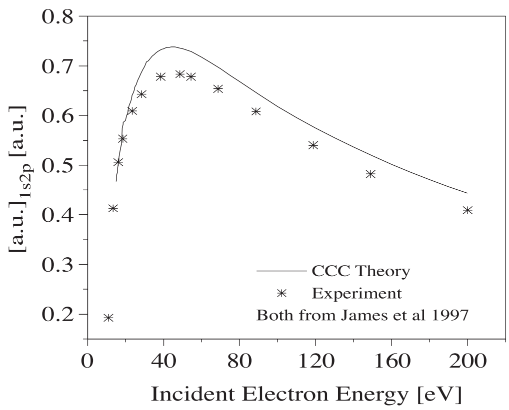

Figure 3. Total cross section for 2p state of atomic hydrogen [19].

Until the beginning of the 1970's experimental work on electron impact excitation was restricted to the determination of cross sections, both differential and total, and measurements of the polarization of light emitted in the radiative decay of excited states. These measurements are important since there are many applications in which electron impact cross sections plays a fundamental role.

However, in both types of experiments it is likely that some important details are lost concerning the description of the excited state charge cloud in terms of collision dynamics. Therefore, a new method was developed in the early 70's called the coincidence method. In such experiments the scattered electrons and the emitted photons are both detected in coincidence. Two different types of experiments can be carried out using the coincidence method. These are angular and polarization correlation measurements.

2. The Experimental Apparatus

The apparatus is of the crossed electron-atom beam type and it is schematically shown in Figure 4. Electrons from an indirectly heated cathode are focussed into a well-defined beam and cross an atom beam from a long narrow capillary (0.5 mm in diameter). Undeflected electrons are efficiently collected in a Faraday cup. The Faraday cup is connected to a picometer and this arrangement allows us to monitor electron beam current during the measurements.

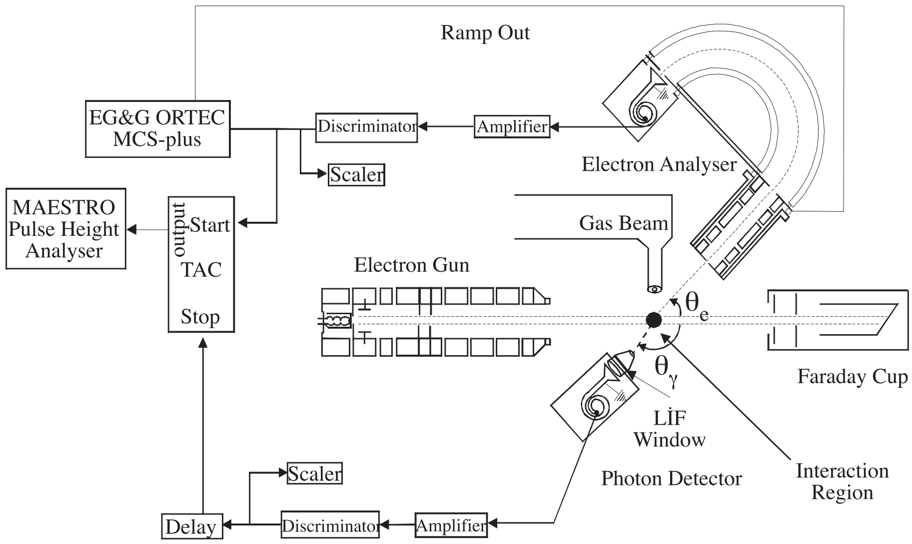

Figure 4. A schematic illustration of the present apparatus.

Electrons scattered through some angle, θ_e, travel through the field free interaction region and are then focussed into the entrance aperture of a 180° hemispherical analyser. The analyser is tuned so that only those electrons which have excited a particular state or group of states as determined by the energy resolution of the system ($\leq$0.8 eV), are transmitted to the channel electron multiplier (CEM) for detection. The decay photons are detected in the photon detector. The electron and photon detectors are independently rotatable in the collision plane about the interaction center. We have used a microwave discharge to produce hydrogen atoms (For details of the apparatus see [8]).

3. The Electron-Photon Coincidence Method

An angular correlation measurement is carried out by fixing the incident electron energy E_0 and the electron scattering angle θ_e and rotating the photon detector over a range of angles, θ_γ.

At any angle of θ_γ, the coincidence signal between scattered electrons and emitted photons is recorded in the following way: After amplification and discrimination of the scattered electron pulses, they are used to start the ramp of a time to amplitude converter (TAC) and delayed photons stop this ramp. Photons are delayed in order to allow the scattered electrons to start the ramp. An electron and photon from the same collision are correlated in time and such a correlation is used to distinguish true coincidence signal from a random coincidence signal due to detection of electrons and photons from different collisions.

In order to determine the number of true coincidences N_T, two time windows are set up in different regions of a time spectrum as shown in Figure 5. If a time window of width Δt is set up over the peak, then this region contains the number of true plus random coincidences $[N_{T+R}]_{\Delta t}$.

A second window, Δt^1, is set up in another region which contains only the number of random coincidences, $[N_R]^1_{\Delta t}$. Therefore the number of true coincidences is

$$_T = [N_{T+R}]_{\Delta t} - [N_R]^1_{\Delta t}\frac{\Delta t}{\Delta t^l}, \tag{1}$$

and the standard deviation of the number of trues ΔN_T can be written as

$$\Delta N_T = [N_{T+R} + N_R(\frac{\Delta t}{\Delta t^l})^2]^{1/2}. \tag{2}$$

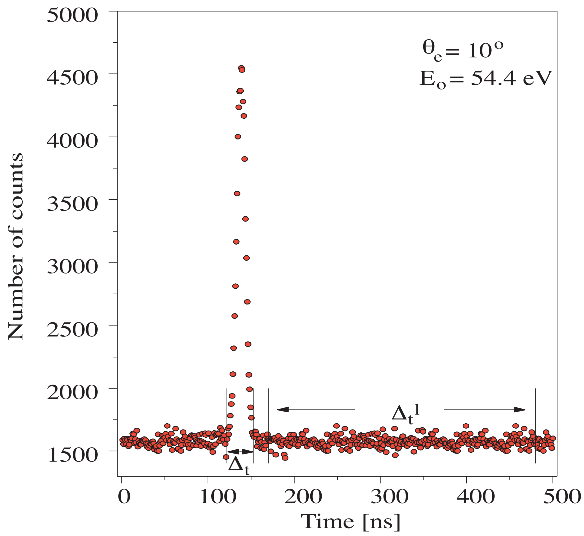

Figure 5. A typical time spectrum.

This result gives only one of the data points of an angular correlation measurement. In order to complete the experiment, the above procedure is repeated for six-seven different angles of θ_γ and this final result is plotted. Then it is needed to define correlation parameters λ and R to describe the excited state. λ and R, which give the information about the intensity of the charge distribution of the excited state are found by fitting the following Equation (3) to the experimental data:

$$I(\theta_\gamma) = K\frac{1}{18}[3\lambda + 11 + 3(1-3\lambda)\cos^2\theta_\gamma - 6\sqrt{2}R\sin 2\theta_\gamma - 3(1-\lambda)\sin^2\theta_\gamma], \tag{3}$$

where K is a constant (for details see [3, 8 and 9]). This expression gives the intensity of the charge cloud distribution of the excited state in terms of the correlation parameters λ and R, as expressed by Morgan and McDowell [10].

4. Results

In this section some results obtained for atomic hydrogen are given. Figures 6 and 7 show the angular correlation data obtained from the coincidence experiment and its comparison with the predictions of Bray and Stelbovics [11] and the previous experimental data of Williams [12]. The legend is as shown in the Figures. It can be seen straight from the Figures 6 and 7 that there is good agreement between the present data and the Convergent Close Coupling (CCC) theory of Bray and Stelbovics [11].

Figures 6 and 7 are only two of a set of measurements at specific scattering angles. The obtained data of λ and R for atomic hydrogen for a wide range of scattering angles using the angular correlation method are presented in Figures 8 and 9. Also the present data are compared with both the available theoretical predictions of the convergent close-coupling method (CCC) [11], the second-order distorted-wave method [13], the intermediate energy R-matrix method [14], the multi-pseudostate close coupling theory [15], the close-coupling calculation using a 17-state target basis including seven exact states and ten pseudostates [16] and the previous experimental results of Williams [12, 18] and Weigold [17]. The legend is as shown in the Figures.

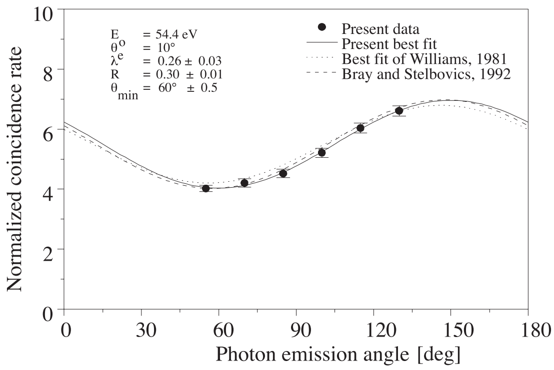

Figure 6. Angular correlation measurements for 2^2P state of atomic hydrogen at the incident energy of 54.4 eV and the electron scattering angle of 10°, and comparison with the corresponding theoretical data.

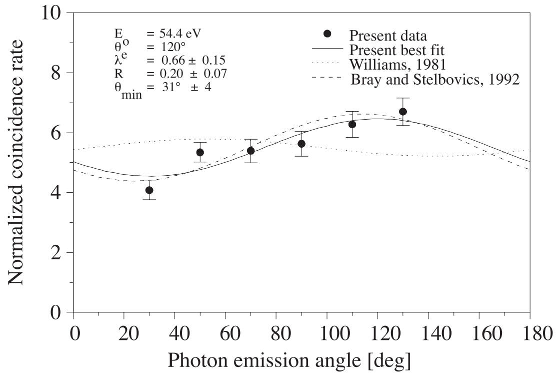

Figure 7. Angular correlation measurements for 2^2P state of atomic hydrogen at the incident energy of 54.4 eV and the electron scattering angle of 120°, and comparison with the corresponding theoretical data.

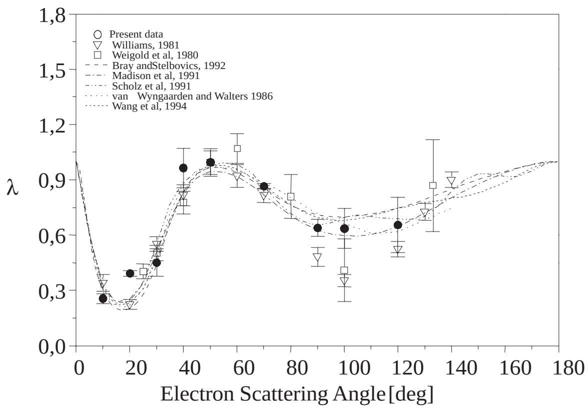

Figure 8. The comparison of present data for parameter λ with the theoretical and previous experimental data.

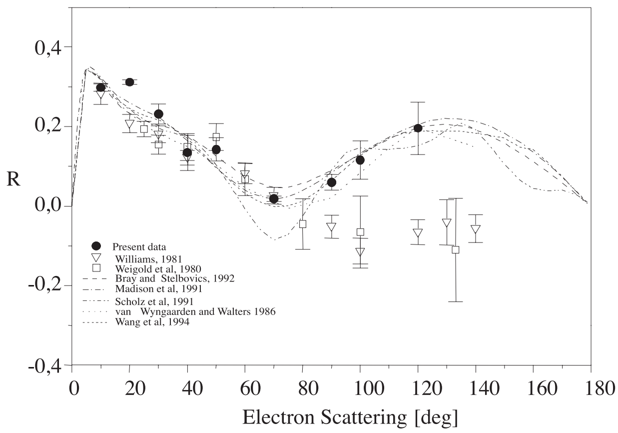

Figure 9. The comparison of present data for parameter R with the theoretical and previous experimental data.

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