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Electron affinity measurement of hydrogen negative ion

Muhammad Usman Ghani[1], M. Imran Jamil[2], Afaq Ahmad[3], Saad Tariq[3]

[1]Department of Physics and Astronomy, Texas Tech University, Lubbock-79415, USA. mughani@ttu.edu

[2]Department of Physics, University of Management and Technology, Lahore-5459, Pakistan. Imran.jamil@umt.edu.pk

[3]Centre of Excellence in Solid State Physics, University of the Punjab, Lahore-54590, Pakistan. draafaq@gmail.com

Correspondence: imran.jamil@umt.edu.pk; Tel.: +923228439947

Abstract

Photodetachment Microscopy experiment was first carried out in the presence of an electric field by Blondel et al in 1996 for Bromine negative ion. It measures the spatial distribution of ejected electron on the detector screen which is a direct view of the spatial structure of the wave function of an atomic electron in the form of ring pattern. From a semi-classical point of view, this ring pattern is formed because of the interference between two electron waves; one is direct while other is reflected from an electric field. Following Blondel's photodetachment microscopy experiment, a formula that displays the Newton Rings is derived using a theoretical imaging technique or hydrogen negative ion near a plane interface. The interface means an elastic plane in the vicinity of the source of photoelectrons. The direct and reflected electron waves in this formula generate the quantum interference in the form of Newton Rings. It is found that the number of rings increases as we increase the photon energy of the laser light.

This finding is in accordance with the very well-known Einstein photoelectric effect which finally provides help to find the electron affinity of the hydrogen negative ion very

accurately.

Keywords: Photodetachment Microscopy; Electric field; Spatial distribution; Ejected electron; Photon energy

Citation: To be added by editorial staff during production.

Academic Editor: Dr. M. Javaid Afzal

Received date: 28th March, 2023

Revised date: 29th April, 2023

Accepted date: 9th May, 2023

Published date: 15th May, 2023

Introduction

A negative ion contains an extra electron and it was first studied by J.J. Thomson as a quantum mechanically weak system [1]. The study of the negative ion is of great interest in the modern era[2]. The process of electron correlation is responsible for a key role of negative ion in the critical test of various theories such as closed orbit theory, Green's function technique, semi classical theory quantum mechanical technique and theoretical imaging method [2-6]. By the virtue of characteristic properties of such negative ions an ideal system for theoretical framework is build. Various aspects of such weak systems have been under consideration including the binding energy, photo detachment cross section and resonance [7].

A solar spectrum was being studied in early 1939 by Wildt and he pointed out that hydrogen is one of the major components of the Sun's matter [8]. From the observation of emission spectrum of celestial objects it comes to the knowledge that there must be present both the neutral and positively charged atoms in them [9]. The formation of negative ions or molecules is the result of continuous collisions of free electrons and the neutral atoms[6]. On the same footings the probability of formation of hydrogen negative ions becomes more because of the linking of single free electron with the neutral hydrogen atom. The solar infrared is characterized by the occurrence of black absorption spectrum. In order to make it sure, Wildt explained the infrared absorption and elaborated that hydrogen negative ions were present in the photosphere of the Sun [10]. The work of Chandrasekhar [11] reinforced the work of Wildt, with precise measurement of binding energy of hydrogen negative ions.

In this research work, we studied the process of photodetachment of hydrogen negative ion in the vicinity of a plane hard wall[7] with the help of theoretical imaging method (TIM). We derived an analytical formula for the calculation of electron affinity of H^- ion. The expectations related to plane hard wall are in agreement with both theoretical and experimental studies in micro junctions in past decades [12-15]. A plane hard wall is different from metallic wall. In this study the electrons followed a straight path with the exception of those being reflected from plane wall[16, 17]. A plane hard wall is characterized by the phase loss of π, when a detached electron is reflected from this wall. The detached electron has two components from H^- for the observer being at large distance[18]. The two components being observed, one propagating directly from H^- and the other is approaching indirectly after being reflected from plane wall[19]. A relation for detached electron flux was calculated by Afaq *et. al*.[20] and this relation is used to obtain the interference pattern in the form of ring pattern. This ring pattern helps us to formulate a simple relation between the number of rings and the photon energy. Finally this analytical formula for the calculation electron affinity of H^- ion is in agreement with experimental result [21].

We organized this paper as follows: in second section of the study, we elaborated the wave function of detached electrons with the help of TIM, proceeded by the process of drawing the results of interference pattern with the help of the relation for electron flux, such interference pattern was also employed for drawing newton rings. In the next section we derived a linear relationship between energy of incident photons and square of newton rings. Conclusions are given in section five.

Photodetatchment microscope of H^- near a plane wall

The study of detachment of hydrogen negative ion near a reflecting surface / wall with the help of theoretical imaging method is considered. This method employs the analytical approach to derive the formulae for total and differential cross sections of the process[20]. A hard wall case is to be considered in this regard. The term hard wall refers to a wall that is responsible for the production of a phase loss of π.

Following figure illustrates the process of photodetachment of hydrogen negative ion near a reflecting surface:

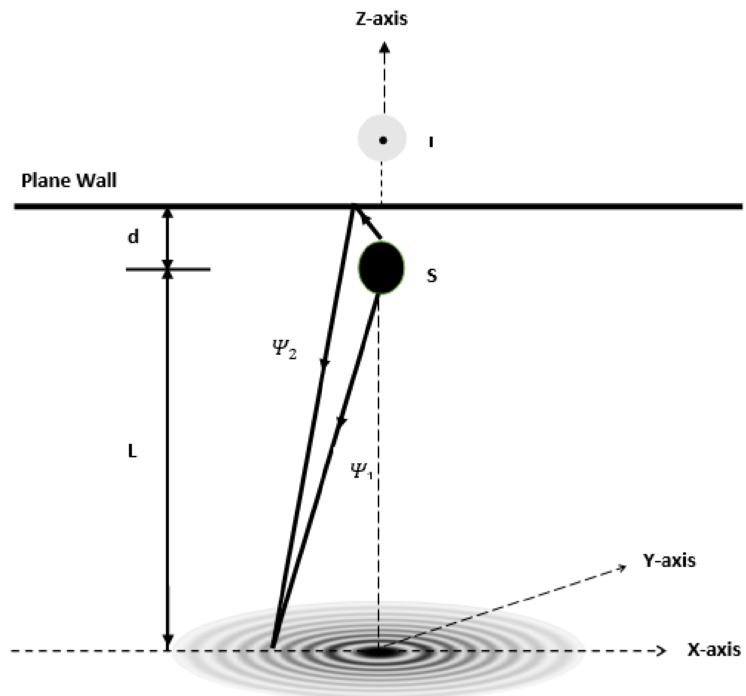


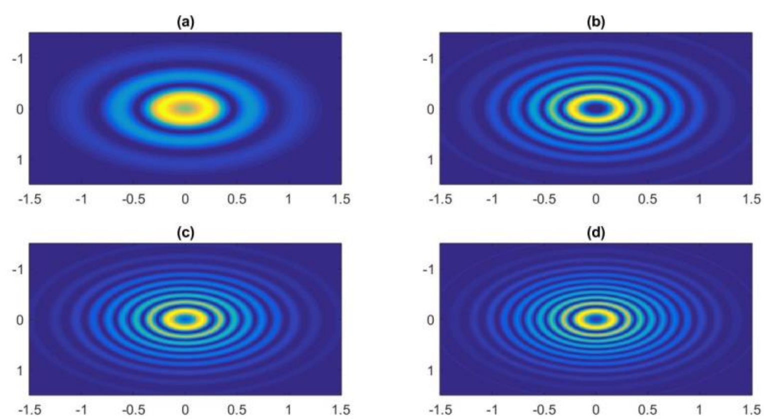
Figure I: The schematic diagram for photodetachment microscope of H^- near a wall.

Fig. I depict that hydrogen negative ion, which is placed along the direction of Z-axis, is acting as a source (S) of detached electron wave. The distance of hydrogen negative ion from the wall is d atomic units, the reflecting surface coincides with the XY-plane. A polarized laser beam along the Z direction is applied for the photodetachment of hydrogen negative ion. Ψ_1 and Ψ_2 are the two components of detached electron wave shown in Fig. I, whereΨ_1 is referred to as direct component and Ψ_2 is the reflected component. Ψ_2 seems to be coming from the image I behind the plane wall.

There are two steps involved in the process of photodetachment, first H^- absorbs the E_{ph} (energy of a single photon) and an outgoing electron wave is generated from it; second the outgoing wave is propagated to a large distance. Suppose $\theta_1 < \frac{\pi}{2}$ be the angle between Z-axis and the direction of motion of the detached electron. Half of the scattered electron wave taken as Ψ_1 will propagate away from the negative ion, with the same angle θ_1, to a large distance. The other half of the wave first propagates to the wall, with an angle greater than $\frac{\pi}{2}$, and then after reflection from the wall it propagates to the large distance. This reflected wave is termed as Ψ_2. A relation for electron flux in radial direction for plane hard wall was calculated by Afaq *et.al.* [20] and given as

$$j_r(r,\theta,\emptyset) = \frac{2k|C|^2 cos^2(\theta)}{r^2}[1 + cos(kd\, cos\,\theta)] \quad (1)$$

According to Eq. (1), it becomes clear that the value of detached-electron flux depends upon the value of $\sqrt{\rho^2 + L^2}$, (where $r = \sqrt{\rho^2 + L^2}$ and $\rho^2 = x^2 + y^2, z = L$) ion-wall distance is d, wall-screen distance is L and the energy of the incident photon is E_{ph}. The peaks corresponding to detached-electron flux obtained for different photon energies will be plotted and this plot indicates that the wall induces oscillations in the spatial electron distribution. Basically, quantum interference is responsible for these oscillations among the direct wave of the source and the wave reflected which seems to be emerging from the image. Such strong quantum



interference pattern is shown in the form of Newton rings. It can be seen from the figure below that number of Newton rings increases as we increase the incident photon energy.

Figure II: The Newton rings using Eq. (1). We take, d = 100 a.u. L = 1000 a. u. and the value of E taken as (a) E=1eV, (b) E=2eV, (c) E=3eV, (d) E=4eV.

The electron affinity of hydrogen negative ion can be calculated by deriving a relation between number of fringes and photon energy. For this purpose, we use the Eq. (1) for the condition of bright fringe or peak. Bright fringe or peak is obtained when there is a constructive interference between direct and indirect waves. Peak is obtained when the factor $cos\left(\frac{2kdL}{\sqrt{\rho^2+L^2}}\right)$ is maximum. Mathematically:

$$cos\left(\frac{2kdL}{\sqrt{\rho^2+L^2}}\right) = cos\, 2n\pi$$

$$\Rightarrow n = \left(\frac{dL}{\pi\sqrt{\rho^2+L^2}}\right)k \qquad (2)$$

Where d, L and ρ are fixed in our physical system.

$$\frac{dL}{\pi\sqrt{\rho^2+L^2}} = constant = c$$

So, Eq. (2) becomes,

$$n = ck$$

We know that,

$$k = \sqrt{2(E_{ph} - E_b)}$$

So,

$$n = c\sqrt{2(E_{ph} - E_b)}$$

Or

$$n^2 = 2c^2E_{ph} - 2c^2E_b \qquad (3)$$

It is a straight line between n^2 *and* E_{ph}.

This indicates that when the value of n is zero, photon energy is equal to the binding energy i.e., electron affinity. Following table shows the number of rings for different values of photon energy.

Table I: Relationship between incident photon energy and Newton rings.

Sr. No.	Photon energy "E_{ph}" (eV)	Number of rings "n"
1	1	4
2	2	7
3	3	9
4	4	11

Results and Discussions

The results have been obtained numerically regarding various incident photon energies along with fixing other parameters as constants. It has been observed that the Newton rings pattern obtained are similar to those obtained through experimental setup. With the increase in the incident photon energy the number of fringes also increase as shown in Fig. III below.

We have plotted below the above table-1 between n^2 and E_{ph} which confirms the straight-line equation and extrapolated the graph when n is equal to zero the electron affinity of hydrogen negative ion is found to be 0.754 eV. This is in agreement with the experimental data[21].

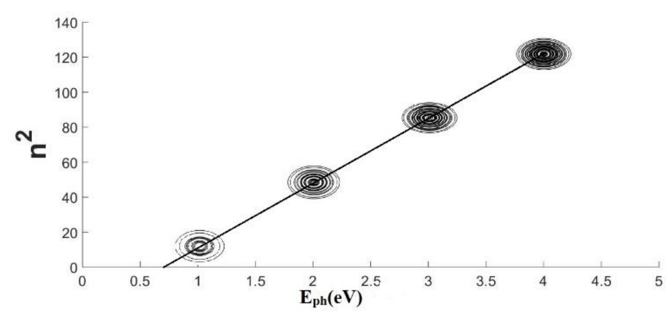


Figure III: Relationship between n^2 and E_{ph}.

Conclusion

The method of photo-detachment microscopy has been used for calculating electron affinity of hydrogen negative ion near a hard wall. The effects of hard wall on the detached electron spectra of a hydrogen negative ion have been found with the help of theoretical imaging method, when illuminated by a polarized beam. Such waves are used for the sake of calculation of detached electron flux at a large distance from the hydrogen negative ion which results in the form of Newton rings pattern on the screen used for observation. The concept of photo detachment is similar to that of photo electric effect.

There is a linear relationship between the square of the number of rings and the energy of the photons. If we extend the line backwards to the zero of the vertical-axis the value of electron affinity of $H^-$is 0.754 eV which is nearly equal to the experimental value [21].

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