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SATURATION EFFECTS IN THE IONISATION OF He BY H⁺ AND He²⁺ IMPACT AT INTERMEDIATE ENERGIES

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Abstract

Projectile charge dependence of double differential ionisation cross section for H⁺ and He²⁺ on He is studied both theoretically and experimentally. The experimental ratio R of the emission induced by 50 and 100 keV/u He²⁺ and H⁺ is compared with calculations from the CDW-EIS model. We report two main effects: a) a decrease of R with increasing angle of electronic emission, b) a sudden enhancement of R in the high energy side of the ECC peak.

Many experimental efforts have been oriented towards the study of the dependence of total electron emission cross sections on the energy and charge of the incident projectile /1/. Coincidence measurements have allowed to separate total cross sections for single ionisation, transfer ionisation and multiple ionisation /1,2/. These measurements show that the total single ionisation cross section σ₁ does not follow the Z²⁺-law predicted by the first Born approximation and that it tends to a finite limit when Z⁺ increases, giving rise to the so-called "saturation effect". From the analysis of such measurements for stripped ions on H and He it was found /3/ that σ₁ can be expressed as a simple function of the reduced velocity \( v_R = v_\perp / Z_e \) (in atomic units). The ratio \( \sigma_{\perp} / \sigma_\parallel \) with \( \sigma_\parallel \) given by the first Born approximation deviates strongly from the \( Z_e^2 \) behaviour for \( v_\perp < 5 \) and decreases exponentially with decreasing \( v_\perp \). In this range (\( v_\perp < 5 \)) we must consider either low energy theories or those containing high perturbative orders.

Recent experimental studies of the projectile charge dependence of double differential electron emission have been made for high velocity C6⁺, O8⁺, Ne10⁺ /4/ and Mo40⁺ /5/ incident on He. Departures from the \( Z_e^2 \)-scaling law were attributed to "two center electron emission" (TCEE) and a comparison with the "Continuum Distorted Wave-Eikonal Initial State" (CDW-EIS) model show good agreement.

The CDW-EIS model proposes an entry channel where the target bound state is multiplied by an eikonal phase that provides the distortion associated with the electron-projectile interaction. In the final state the electron feels the Coulomb fields of the projectile and the residual target. The corresponding wave function is written as a product of two continuum states, one centered on the projectile and the other centered on the target.

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These initial and final wavefunctions satisfy the correct asymptotic conditions. In this way, the initial and final states introduce TCEE by considering the distortion of the electronic states due to the presence of the projectile potential.

The aim of the present work is to analyze the projectile charge dependence of double differential electron distributions using $H^+$ and $He_2^+$ impinging on He at intermediate energies. We compare our experimental results with those obtained with the CDW-EIS approximation.

We have measured double differential electron distributions for 50 and 100 keV/amu $H^+$ and $He_2^+$ impinging on He. In order to see the projectile charge dependence on the electron emission we obtained double differential ratios $R(E_\alpha, \theta)$, dependent on $\theta$, the electron angle of emission, and $E_\alpha$ the electron energy by dividing the double differential electron distributions resulting from $He_2^+$ impact and that corresponding for $H^+$.

Measurements were performed with a coaxial cylindrical mirror spectrometer designed in our laboratory /7/ which allows us to cover in a continous manner the full angular range of electron emission, including small angles. The He-target was provided by a hypodermic needle of 0.25 mm bore. Deformations in measured electron distributions atributable to extended gas target effects were reduced to a minimum as was shown previously /8/. Recent measurements of double differential cross sections for $H^+$ impact on He, performed with this spectrometer, were compared with those of other authors and they have been reported elsewhere /8/.

In figure 1 and 2 we present the experimental double differential ratios $R(E_\alpha, \theta)$ divided by 4 for 50 and 100 keV/amu compared with those obtained with the CDW-EIS approximation. A complete discussion of the error involved in this experiment was given in /9/.

We first take account for the experimental results and describe common features. In figure 1 and 2 we observe two strikingly different behaviours of $R(E_\alpha, \theta)$:

i) For electron energies lower than the energy of the "electron capture to the continuum" (ECC) peak the ratio decreases as the angle increases and it has a weak electron energy dependence.

ii) At the energy of the ECC peak the ratio for $\theta=0^\circ$ presents an abrupt step which rises above $R=4$, the first Born prediction. For higher electron energies this enhancement is observed to decrease for the case of 100 keV/amu, while it remains up for 50 keV/amu.

The CDW-EIS results show the same qualitative behaviour as the experimental data. For 100 keV/amu the $50^\circ$ ratio are in quantitative agreement, but at small angles the theory gives a smaller overall values. This could be attributed to the fact that the CDW-EIS model underestimates the cross section for small angles as has been previously observed for the ionisation of He by $H^+$ impact at intermediate energies /10/.

For 50 keV/amu discrepancies increment because of at this low projectile energy the CDW-EIS approximation falls down and the contribution from transfer ionisation and double ionisation to the measured electron emission become larger. In particular, single ionisation of He by 50 keV/amu $He_2^+$ contributes only 65% of the total electron emission /1/.

In conclusion we have observed large departures from the $z^2$-scaling law in the double differential electron emission from He by light low charge projectiles at intermediate energies. The main experimental features were shown to be qualitatively reproduced by the CDW-EIS approximation.
Figure 1: Ratio $R(E_e, \theta)$ divided by $2^2$ between the double differential electron emissions obtained with 50 keV/amu He$_2^+$ and H$^+$ impinging on He as a function of the electron energy. Experimental data: (o) $\theta=0^\circ$; (\triangle) $\theta=20^\circ$; (+) $\theta=40^\circ$. Theory: (---) CDW-EIS approximation; (----) first Born approximation.

Figure 2: Ratio $R(E_e, \theta)$ divided by $2^2$ between the double differential electron emission obtained with 100 keV/amu He$_2^+$ and H$^+$ impinging on He as a function of the electron energy. Experimental data: (o) $\theta=0^\circ$; (\triangle) $\theta=30^\circ$; (+) $\theta=50^\circ$. Theory: (---) CDW-EIS approximation; (----) first Born approximation.
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