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Dressed projectile charge state dependence of differential electron emission from Ne atom

S Biswas[1], J M Monti[2], R D Rivarola[2] and L C Tribedi[1]

1 Tata Institute of Fundamental Research, Homi Bhabha Road, Colaba, Mumbai 400 005, India

2 Instituto de Física Rosario (CONICET-UNR), Universidad Nacional de Rosario, 2000 Rosario, Argentina

E-mail: shubhadeep@tifr.res.in, lokesh@tifr.res.in

Abstract. We study the projectile charge state dependence of doubly differential electron emission cross section (DDCS) in ionization of Ne under the impact of dressed and bare oxygen ions. Experimental DDCS results measured at different angles are compared with the calculations based on a CDW-EIS approximation using the GSZ model potential to describe projectile active-electron interaction. This prescription gives an overall very good agreement. In general a deviation from the q^2-law was observed in the DDCS. The observations crudely identify the dominance of different projectile electron loss mechanisms at certain electron energy range.

1. Introduction

Collision with dressed ions is considerably different than bare ion impact. In that case, additional phenomena like projectile ionization or excitation can take place due to target electron-projectile electron interaction [1, 2, 3, 4, 5]. Depending on the impact parameter of the collision, it also can enhance or reduce the target ionization cross section [6]. But, the fact is that relatively lesser number of systematic studies are available involving dressed ion projectiles compared to the bare ion impact studies [7, 8, 9, 10], particularly in the double differential cross section (DDCS) level. Especially, there are very few references [3, 11, 12, 13, 14], which investigated in the low ejected electron energy region. As far as theoretical understanding is concerned most of the earlier descriptions approximated the presence of the projectile electrons by a reduced effective projectile nuclear charge. But this prescription did not give very good result. Recently, it has been shown by Monti *et. al.* that along with the asymptotic long range Coulomb interaction, separate interaction term is necessary to incorporate the short range effect of the projectile electrons [15, 16].

In this report, we provide a comparative analysis of both the experimental and the theoretical findings for the electron emission mechanism of Ne atom following 3.75 MeV/u O^{5+}, O^{6+} and O^{7+} ion impact, in the absolute DDCS level. For comparison, the bare ion data are also provided. On the theoretical side, following the above mentioned reference [15, 16], we have carried out calculations using Green-Sellin-Zachor (GSZ) interaction potential [17] in the continuum distorted wave-eikonal initial state (CDW-EIS) approximation framework [18, 19]. We also provide a comparison with the Born approximation, which works well for the bare ion projectile charge state dependence, especially in the total cross section level.

2. Experimental Details

The present experiment was carried out with the 3.75 MeV/u oxygen ions available from the BARC-TIFR 14 MV tandem Pelletron accelerator facility in Mumbai, India. The main scattering chamber was maintained at a base vacuum of about 2×10^{-7} Torr. During the interaction with the target the chamber was flooded with Ne gas at a static pressure of 0.15 mTorr. We used an electrostatic hemispherical analyser of 6% energy resolution [20] for energy analysis of the electrons, and these were detected by the channel electron multiplier (CEM) detector. Further details of experimental setup is available in Ref. [20]. In this case the electrons are detected in the energy range of 10 eV to 300 eV at three different angles, namely 30°, 90° and 150°. The maximum statistical uncertainty in the measurement was estimated to be about 15%. Other than that the main contribution to the error is from gas pressure fluctuation which was about 7%.

3. Results and Discussions

Here we have used the *prior*-version of the CDW-EIS model for single ionization by dressed projectile[15, 16]. It has been shown that for dressed projectiles, it is necessary to incorporate the effect of projectile electron separately, particularly for the short range interactions. Therefore, to serve this purpose, the projectile potential, V_P, is approximated by a parametric GSZ potential [17], which contains a short-range term and a Coulomb long-range term depending on the charge state q of the projectile:

$$V_P(s) = -\frac{1}{s}(Z_P - q)[H(e^{s/d} - 1) + 1]^{-1} - \frac{q}{s} \tag{1}$$

In (1), H and d are the parameters that depend on the nuclear charge Z_P of the projectile and the number of electrons present in it. Also s is the distance between the target active electron and the projectile nucleus.

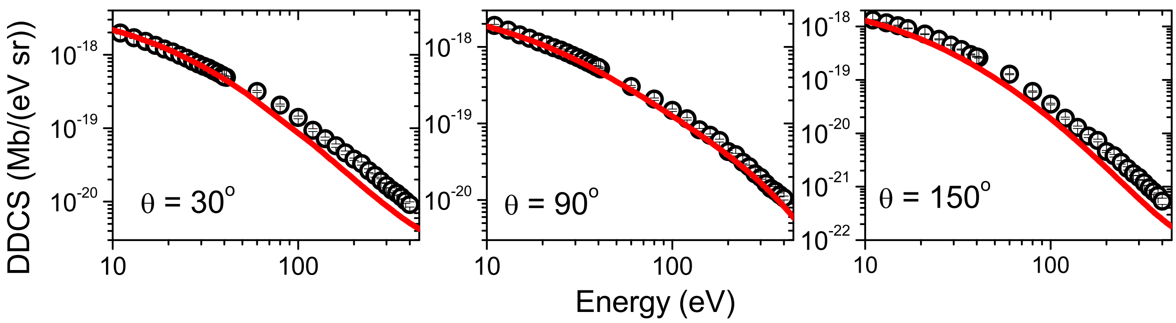

Figure 1. Energy distributions of DDCS for O^{6+}. Solid line denotes the CDW-EIS pridiction.

Fig. 1 shows the typical energy distribution of DDCS for O^{6+} at three different angles. In general, the qualitative features for other charge states are also quite similar. As far as the theoretical agreement is concerned, at 90°, it is very good throughout the entire energy region. For 30° and 150°, in the low energy part, the agreement is quite well. But with increasing energy it gets deteriorated. The theoretical prediction underestimates the DDCS values obtained from the experiment. It is worth mentioning here that for large multi-electronic targets similar kind of deviation was noticed at higher electron energies earlier even for the bare ion impact[21].

In Fig. 2, we have plotted the DDCS as a function of q, at fixed electron energy and at fixed ejection angle. It is evident that the qualitative behaviour of the plots changes a lot with energy and ejection angle. For example, for all angles, at low energy like 11 eV where the target ionization is the dominant process, the DDCS increases gradually with increasing q. This kind of behaviour is expected from the projectile screening argument. As the low energy part of the spectrum corresponds to the large impact parameter collisions, the active electron would be influenced by the projectile as a whole, i.e. by a screened nuclear charge for dressed projectile. Therefore, with increasing q the perturbation strength increases which in turn increases the cross section. For 100 eV plots the behaviour is similar, though the difference between the dressed projectile-DDCS and the bare projectile-DDCS is smaller compared to the earlier case. This can be easily seen for 150°. This decrease can be attributed to the fact of reduction of projectile screening. As the higher energy electrons are emitted in relatively smaller impact parameter collisions, the active electron would see relatively less screened dressed projectile. As a result the cross sections corresponding to the dressed projectiles become comparable to that of the bare ion projectile. Similar discussion of projectile screening effect is available in Ref. [14]. For higher

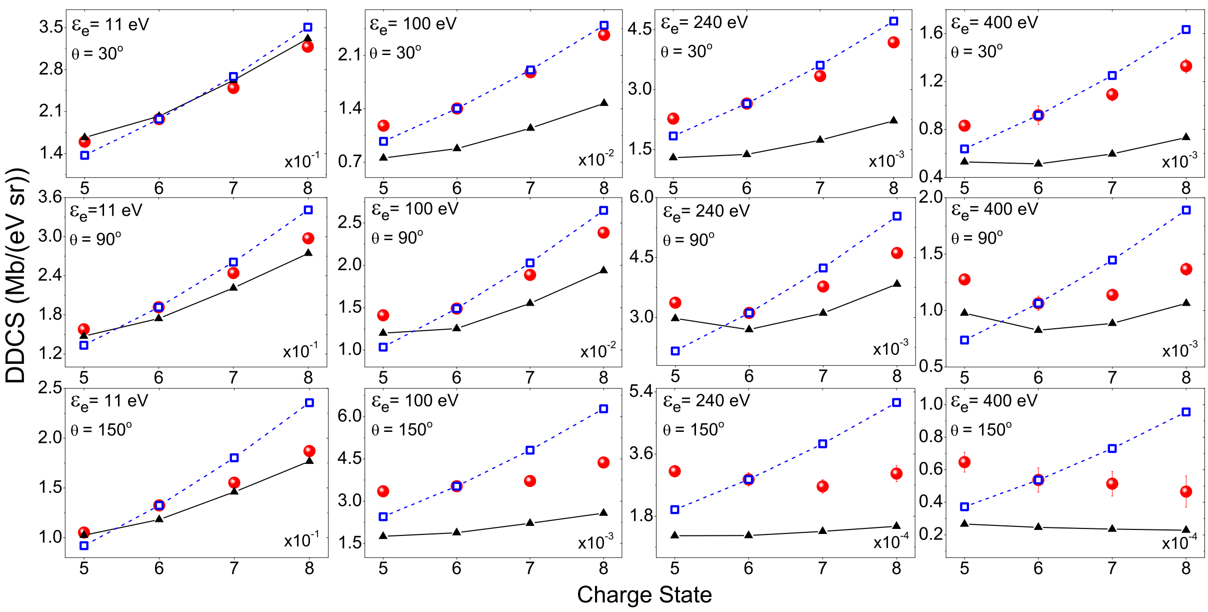

Figure 2. Charge state dependence of DDCS at different observation angle and for different ejected electron energy. The solid spheres represent experimentally measured data. The solid triangles denote the CDW-EIS predictions. The squares denote the q^2-scaling behaviour normalized at the DDCS value corresponding to O^{6+} (i.e. $q = 6$). The vertical scale of each plot is to be multiplied by the factor given at the right hand side corner below of the respective plot. Solid dots represent experimental results.

energies like 240 eV the distribution shapes are considerably different than that of the earlier. The noticeable change is that, for 90°, the DDCS corresponding to O^{5+} is little higher than that of O^{6+}. For 150°, both O^{5+} and O^{6+} DDCSs are larger than that of O^{7+}. Similar behaviour is also observed for 400 eV at 90° and 150°. In fact at 150°, the DDCS distribution shows completely decreasing behaviour with increasing q. This apparently different behaviour can be due to the dominance of other ionization mechanisms. It is well known that in the high energy range the projectile ionization contributes to the electron emission spectra [3]. Other than that the simultaneous ionization also plays an important role. Evidently, for lower q, i.e. with more number of electrons with the projectile nucleus, the probability of the above mentioned processes increases. Therefore, in this higher energy region, there is a mutual competition between the target ionization and the projectile or the simultaneous ionizations. The Born approximation predicted q^2-scaling law (denoted by squares in the figure), to some extent fails to reproduce the experimental findings especially at backward angle and for higher energies. For example, at 240 eV and 150° plot, the predicted behaviour is opposite to the observed behaviour. At lower energies the agreement is relatively better. On the other hand, the CDW-EIS prediction (denoted by solid triangles in the figure) reproduces the qualitative behaviour quite well, more or less for all angles and for entire energy range. The absolute values also match well with the experimental values for 11 eV. For other three energies, the theoretical values underestimate the experimental ones to some extent, particularly for extreme angles.

4. Conclusion

We have measured the projectile q-dependence of DDCS for electron emission in ionization of Ne atom by dressed O-ions of energy 3.75 MeV/u. The CDW-EIS model along with the GSZ model potential, gives an overall good agreement with the experiment. This emphasizes the importance of proper inclusion of the effect due to the projectile electrons in the theoretical models. The Born predicted q^2-scaling does not work so well to describe the DDCS data particularly for the higher energies and at the backward angles.

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