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POST COLLISION INTERACTION OBSERVED AT HIGH-ENERGY ION-ATOM COLLISIONS

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Abstract — The shape of the Ne KL2L3 (1D2) diagram Auger line has been investigated in the 5.5 MeV/u N2+ and Ne2+-Ne collisions. An asymmetric line shape has been found showing up a tail on the high energy side of the line, while the shape of the line due to the 1s2e2p(4P)-1s2(1S) transition from the Li-like metastable initial state measured in the 5.5 MeV/u Ar14+-Ne collision was symmetrical. The line shape calculated according to a post collision effect due to the slowly receding ejected electrons shows a very good agreement with the measured line shapes.

Introduction — The post collision interaction (PCI) was first observed by Barker and Berry1. They investigated the energy shift and broadening of the autoionization lines of He excited by few keV He+ projectiles. They concluded that this effect is the result of the interaction between the Coulomb field of the outgoing He+ ion and that of the doubly excited neutral He atom.

Later on many authors studied the effect of the PCI on the shape and energy of the emitted Auger lines experimentally2-8. The theoretical models elaborated for the case of ion-atom collisions describe well the post collision interaction between the bombarding ion (or the ejected photoelectron in case of photon excitation) and the decaying target ion9-16.

Up to now the highest projectile energy has been used by Arcuni5 to investigate the PCI. He investigated the effect of the post collision interaction on the (2p2) 1D and (2s2p) 1P autoionization transition as a function of the emission angle in the 0.5 MeV/u He6+-He and Li11+—He collisions. His results were well described by the correct theoretical treatment of van der Straten and Morgenstern15 who took into account the post collision interaction of the decaying target and the slowly receding projectile.

In the past few years we have measured a series of high resolution Ne K-Auger spectra in high-energy (5.5 MeV/u) ion-atom collisions17,18,19. Evaluating these data we found, that different line shapes should be used to describe the metastable and normal Auger lines. This indicates the presence of PCI in these collisions, although the velocity of the projectile is high enough to consider its interaction with the decaying target ion.
to be negligible. However, the possibility of a post collision interaction between the decaying target ion and the electrons ejected in the collision should be considered, since a significant part of the ejected electron spectrum is of relatively low energy.

In this paper on the examples of the 5.5 MeV/u $N^3\text{He}^-\text{Ne}$ and $Nd^+-\text{Ne}$ collisions it was aimed to show that the effect of the PCI is not negligible even at relatively high-energy heavy-ion-atom collisions.

**Experimental arrangement** - The measurements were performed using the electrostatic electron spectrometer ESA-21. The spectrometer is the combination of a two electrode spherical decelerating lens, a spherical mirror, and a double pass, double focussing cylindrical mirror. The spherical mirror serves as a transport system between the decelerating system and the main analyzer - the cylindrical mirror. The gas-beam target is located in the centre of the spherical deceleration lens. The spherical deceleration and transport makes possible the simultaneous measurement of the energy and angular distribution, although this feature was not exploited in the present evaluation of the measured data. The measurements were performed in the fixed pass energy mode, by varying the deceleration. This mode of operation ensures an energy independent instrumental line shape and detector efficiency, and at the same time a good energy resolution ($\Delta E < 10^{-4}$ $\leq \Delta E \leq 10^{-4}$). The complete experimental arrangement is shown in Kádár et al.

**Results and discussion** - Fig. 1 shows the supposedly by PCI influenced diagram line shapes ($KL_2L_3$) measured in the Ne K-Auger spectrum emitted in the 5.5 MeV/u $N^3\text{He}^-\text{Ne}$ (Fig. 1(a)) and $Nd^+-\text{Ne}$ (Fig. 1(b)) collision as well as the calculated fitting line shape (identical for each component at the same instrumental resolution). For comparison also the shape (supposedly unaffected by PCI) of the line due to the transitions $ls_12a_12p_1(4P_{1/2},3/2)-laa(1S)$ from the long-living ($\tau \approx 1.8, 0.4, \text{and} 10.4 \text{ns}$) metastable $Li$-like initial states of neon is shown (Fig. 1(c)) together with a calculated PCI affected line shape which cannot fit the experimental one. The metastable transition was measured in the $Ar^{16+}-\text{Ne}$ collision at the same projectile velocity as the others. This line is due to three close lying transitions. The metastable line shape represents essentially the instrumental one, since the natural line width is negligible compared to the instrumental contribution. The line shapes in Fig.1 have been measured with a pass energy of 175 eV. This corresponds to an instrumental FWHM of 0.88 eV. To show the effect of reducing the instrumental contribution to the line width in Fig. 2(a) and 2(b) we present the shape of the line due to the $KL_2L_3 (2S - 1 D)$ transition as measured with a pass energy of 100 eV in the 5.5 MeV/u $N^3\text{He}^-\text{Ne}$ and $Nd^+-\text{Ne}$ collisions. The reduction of the pass energy decreased the instrumental contribution to the line width by cca 43% (this corresponds to an instrumental contribution of cca 0.5 eV), while the resultant FWHM of the line was decreased only by 23%.

The shape and position of a specific line may change due to the space charge built up in the target gas and due to the effect of post collision interactions. The magnitude of the space charge in the target gas beam (if present at all) depends on the pressure of the gas in the volume crossed by the ion beam, the flux of projectile ions, the cross section of ionization at the given effective projectile charge and velocity. The magnitude of the effect of the PCI depends on the velocity and charge of the projectile as well as on the velocity distribution and the number of electrons ejected in the collision (considering also multiple ionization).
Fig. 1. Ne $K\ell_2\ell_3$ diagram transition measured with 0.88 eV instrumental resolution from

a. the 5.5 MeV/u $N^{2+}-Ne$ and

b. $Ne^{++}-Ne$ collision;

c. the Ne $1s2s2p\ (^4P)-1s^2\ (^1S)$ metastable transition from the $Ar^{16+}-Ne$ collision together with the calculated PCI affected line shape which do not fit well the experimental one. Circles represent the experimental points, the continuous line the fitted curve and the individual fitting components are drawn with dashed line. On the top insert the residual is shown.

In the following we show that in our case the asymmetry in the measured line shapes is due mainly to the PCI between the slowly receding ejected electron and the decaying target ion and not to the space charge in the target or to the PCI with the fast projectile.

a. Experimental parameters influencing the shape of the measured lines

1. All the line shapes have been measured approximately at the same projectile velocity (± 3%).

2. The energy analyzer unit of the spectrometer - the cylindrical mirror - was working
with unchanged input and output slit width settings throughout the measurements. (The relative magnitude of the electronoptical aberrations is the same in all the investigated cases.)

b. Experiences

1. The shape of the diagram lines was found to be asymmetrical with a tail on their high energy side.

2. The comparison of the approximately symmetrical shape of a metastable line (Fig. 1(c)) and that of the diagram lines measured with the same spectrometer settings (Figs. 1(a) and 1(b)) proves, that the asymmetry found in the shape of the diagram lines is not caused by any instrumental effect like target gas charging, asymmetrical instrumental line shape and so on.

3. The experimental diagram line shapes obtained by using the same pass energy and deceleration values (Figs. 1(a) and 1(b) and Figs. 2(a) and 2(b), respectively) are in pair identical and the same holds for their position, too. The similarity of the shapes shown in Figs. 2(a) and 2(b) measured under identical conditions except for the projectile charge proves that no projectile charge effect is present, i.e. it is not probable, that the projectile PCI would have a significant contribution to the observed asymmetry. Knowing this the comparison of the lines in Figs. 1(a) and 1(b) measured at different target pressures shows that there is no space charge effect present.

On the basis of the above experimental facts it seems to be very probable that the asymmetry found at the diagram lines in these high-energy ion-atom collisions is not caused by any instrumental effect. The fact, that the observed line shape does not depend on the charge of the projectile ion, supports the hypothesis, that this effect is caused by the post collision interaction with the ejected electrons. Although the projectile itself is fast enough to leave the neighbourhood of the target quickly, but many of the electrons ejected in the collision are of low energy (low velocity) and have enough time to interact with the field of the decaying atom. By accepting this explanation the above mentioned experimental facts can be described adequately by PCI since the interaction with these slow electrons causes energy shift, broadening and an asymmetric line shape with a tail in its high energy side.

When investigating the shape of the line obtained from the $KL_2L_3$ diagram Auger transition one considers only the single K ionization (with no other simultaneous excitation or ionization). In this simplest case the post collision interaction takes place between the slowly receding single ejected electron and the field of the decaying target ion. The line shape produced by this interaction can be calculated like in the case of the photoelectron emission, taking into account one slow electron. Since the electrons emitted in the process have a continuous energy distribution this distribution should be taken into account by averaging over the total energy range covered by the electron spectrum. An approximation of the exact averaging is to simply calculate the average electron energy and to use this energy as the energy of the electron ejected from the Ne 1s shell. The energy distribution of the ejected electrons has been calculated according to the BEA as formulated by Ziem in his dissertation (Freie Universität Berlin, 1974), and the average energy of the ejected electrons was found to be 1200 eV. For the natural line width of the diagram transition 0.27 eV$^2$ has been used. We have calculated the effect of PCI according to the model of Niehaus and Zwakhals$^{11}$ elaborated for photoelectron emission. This model, as it was shown by Tulkki et al$^{16}$ describes the line shape and
the energy shift in good agreement with their quantum mechanical approximation. The
line shape calculated according to the procedure described above was convoluted with
the instrumental line shape (approximated by a Gaussian). The width of the Gaussian
instrumental line shape was estimated from the mechanical setting of the slits of the
cylindrical mirror and from its dispersion, as well as from the pass energy of the cylin-
drical mirror (determined by the actual electrode potential used at the measurements).
The mechanical parameters were held constant in course of the above measurements, the
only parameter changed between the measurements of the spectra in Fig. 1 and 2 was
the pass energy.

The value of the Gaussian width has been estimated in the following way. From the
mechanical dimensions of the cylindrical mirror a relative line width has been calculated,
and this value multiplied by the actual pass energy gave the total Gaussian instrumental
width. The estimated relative line width was $4.5 \cdot 10^{-3}$. The electronoptical aberrations
should make this value a bit larger than the estimated one. To find its real value, we
fitted this parameter to the line shape of the diagram transition obtained in the $Ne^+ - Ne$
collision measured with 0.5 eV instrumental resolution (Fig. 2(b)), using the calculated
PCI affected natural line shape. The fitted value of this parameter was slightly higher
than the estimated one - $5 \cdot 10^{-3}$ - in good agreement with our expectation. Using this
value to the description of the line shapes shown in Figs. 1(a), 1(b) and 2(a) a good
agreement has been achieved between the experimental and theoretical line shapes in
all these cases, by using the same PCI distorted shape (in the case of projectiles of the
same velocity the shape of the ejected electron spectrum is independent on the projectile
charge).

**Conclusions** - The agreement between the calculated and measured diagram line
shapes supports the hypothesis that the post collision interaction is not negligible even in
the case of high-energy ion-atom collisions. The determining role here is played by
the PCI between the slow ejected electrons and the decaying target ion. This is the
other extremity in contrary to the case of slow projectiles, when the PCI between the
projectile and the decaying target ion is overwhelming the effect of the PCI with the
ejected electrons.

A consequence of this is that the process of ionisation cannot be separated com-
pletely from the process of decay even in the high-energy ion-atom collisions. A further
consequence of the PCI in the ion-atom collision processes is that the angular anisotropy
found in these collisions can be influenced also by the asymmetric distribution of the
momentum directions of ejected electrons, which produces a new quantization axis.

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**References**

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