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CHARACTERIZATION OF MULTIPLE IONIZATION PROCESSES BY MEANS OF AUGER SPECTRA MEASURED IN Ne^{3+}, Ne^{10+}, Ar^{6+} (5.5 MeV/u) - Ne COLLISIONS

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Multiple ionization is the dominant process involved in high energy heavy ion atom collisions. By assuming that the probability Q_n for the simultaneous production of n L shell vacancies and one K hole is given by a binomial distribution, one can determine the L shell vacancy production probability per electron, p. These parameters were given by several authors for neon from the analysis of the X ray [1,2,3] and Auger spectra [4,5,6] produced in energetic heavy ion atom collisions. Recently these data have been compared with the corresponding theoretical calculations of Becker et al.[7,8], and Sulik et al.[9]. Although the vacancies are produced by exciting electrons into the continuum as well as to higher shells, these two processes cannot usually be distinguished in the evaluation of p_L from the measured spectra. In high resolution Auger spectra one can separate in certain cases the satellite lines produced in pure ionization events from those due to ionization and excitations to higher bound states. In the present study we try to assess the role of excitations to higher bound states in the multiple vacancy production.

The resolution of our triple pass electrostatic electron spectrometer [10,11] has been considerably improved by incorporating an additional deceleration system into the first spherical stage of the spectrometer. In all other respects the experimental arrangement was practically the same as in our earlier study [6]. The beam current from the cyclotron U-300 (Dubna, JINR) was about 100 nA at the neon gas target beam for the Ne^{3+}, Ne^{10+} and Ar^{6+} ions of 5.5 MeV/u impact energy.

Due to the high resolution of the electron spectrometer (about 1 eV) it was possible to distinguish individual transitions from each other within the satellite group around the kinetic energy of 785 eV, which consisted mainly of $KL\text{-}L_{2,3}L_{2,3}$ transitions with no excited spectators in the higher shells. The spectra measured at the observation angle of 165 degrees for the three projectiles indicated above are shown in fig. 1. The Auger transitions observed in the 782–805 eV energy range have been identified as shown in the figure. For details see reference [12]. The spectrometer collects electron spectra measured simultaneously at 13 different angles ranging from 0 to 180 degrees. For determinating the relative intensities the data obtained from all the angular channels were taken into consideration, so that the anisotropic angular distributions of the lines did not affect the results. Table 1 presents the measured relative intensity values normalized to the KL_2L_3 diagram line in the same spectrum, as well as the branching ratios used in determinating the relative populations. These branching ratios were taken from the calculations of Schmidt [13] in the case of the multiplets of the $1s^12s^12p^6$ vacancy configuration and from Krause et al.(1971) in the case of the $1s^12s^22p^5$ one. Using the relative populations of the $1s^12s^12p^5$ and $1s^12s^22p^6$ vacancy configurations obtained from the measured intensity ratios the average ionization probability values for one electron were determined in the L–shell and separately in the 2p and 2s subshells of neon in the 5.5 MeV/amu collisions of Ne^{3+}, Ar^{6+} and Ne^{10+} with Ne. For this purpose we made use of the binomial distribution supposed to be valid for configurations involving no excited electrons.

Since in estimating the values of the ionization probabilities per electron we use only the intensity ratio between the transitions of initial vacancy configurations which have one or zero hole in the L–shell and those in the K–shell with no electron excited to higher bound states,our evaluation procedure implies the following.

a/ The p_L values determined from X-ray measurements with moderate resolution (where the instrumental resolution usually does not allow one to separate ionization satellites from those originating from vacancy configurations containing holes produced by excitation) as well as those obtained from the ratio of the intensity of the total K–Auger spectrum to the diagram intensity systematically tend to be higher than our values estimated from the present measurements, since they provide the vacancy production probability per electron (let us denote it by $\check{p}_L$).

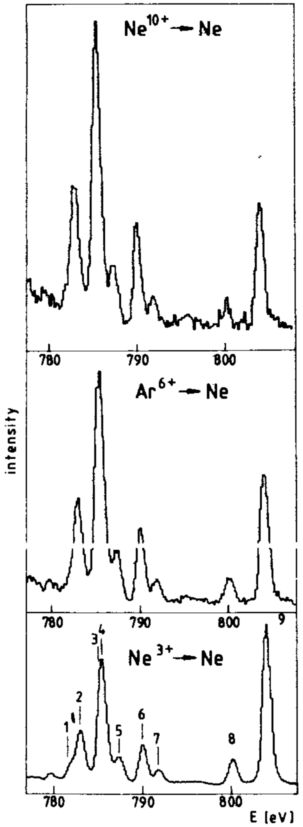
b/ The ionization probability values obtained directly from the populations of the configurations containing no electrons excited

Table 1

Relative intensities of the Auger transitions determined in the present study and normalized to the KL_2L_3 diagram transition in the same spectrum, and the branching ratios taken from Schmidt [13] in the case of the multiplets of the $1s^12s^12p^6$ vacancy configuration and from Krause et al.[14] for the multiplets of the $1s^12s^22p^5$ configuration (for the notation see [15]).

Transition	Projectile			Branching ratio
126 sp(^2S–^3P)	0.115(4)	0.16(1)	0.21(9)	0.0562
125pp(^3P–^2P)	0.310(5)	0.76(1)	1.12(9)	0.218
125pp(^3P–^2D)	0.59(4)	1.38(9)	2.0(1)	0.408
116pp(^3S–^2D)	0.31(4)	1.66(8)	0.85(7)	0.853
125pp(^1P–^2P)	0.149(6)	0.34(3)	0.51(4)	0.226
125pp(^1P–^2D)	0.258(5)	0.56(2)	0.78(4)	0.452
116pp(^1S–^2D)	0.082(3)	0.17(2)	0.21(4)	0.589
126pp(^2S–^1S)	0.168(4)	0.20(2)	0.21(3)	0.095
126pp(^2S–^1D)	1.	1.	1.	0.550

Fig. 1. A part of the Ne K Auger spectrum from the 5.5 MeV/u Ne^{3+}– Ne, Ar^{6+}– Ne and Ne^{10+}– Ne collisions.
a. diagram lines: 1=126pp(^2S–^3P), 8=126pp(^2S–^1S), 9=126pp(^2S–^1D)
b. satellite lines: 2=125pp(^3P–^2P), 3=125pp(^3P–^2D), 4=116pp(^3S–^2D), 5=125pp(^1P–^2P), 6=125pp(^1P–^2D), 7=116pp(^1S–^2D).



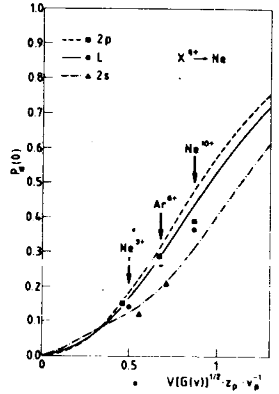


Fig. 2. The experimental and theoretical [16] values of the ionization probability per electron.

into bound states are in fact conditional ones (we denote them by $p_L^{i'}$) which have to be multiplied by the probability of the condition itself (namely that no excitation to higher bound states occurs) to obtain p_L^i, the real ionization probability per electron. The probability of having no excitation is given by $1-(p_L^v-p_L^i)$ in the case

of the total L-shell. The values of the vacancy production probability per electron (p_L^v) obtained from the total K-Auger (including the KLM group)/diagram ratio were used for the estimation of p_L^i. For the total L-shell we get the ionization probability per electron according to

$$p_L^i = \frac{p_L^{i'}(1-p_L^v)}{1-p_L^{i'}} .$$

For deriving the separete L-subshell ionization probabilities per electron one has to know the corresponding subshell vacancy production probabilities per electron. From our spectra only p_L^v, the vacancy production probability, could be extracted for one electron in the total L-shell but not that in the subshells. Instead, subshell ionization probabilities have been estimated by supposing the constancy of the ratio of the vacancy production probability to that of ionization for the subshell concerned.

c/ The probability values obtained this way correspond to the probability that in the case of a given single K ionization one vacancy is created simultaneously in one of the L subshells by exciting the L-electron into the continuum (or the L-electron captured by the projectile).

d/ This ionization probability value will differ from that determined by fitting a binomial distribution to the populations of all the KL^n vacancy configurations containing no electrons excited in bound states lying higher than the L-shell, since the inclusion of higher n values means the inclusion of the effect of the increased binding energy values and this effect presumably decreases the value of the ionization probability.

The obtained results are summarized in Table 2. Since the velocities of the different projectiles are the same, changes in the ionization probability values are due only to differences in the kind, structure and charge of the projectiles.

In fig. 2 the present experimental ionization probability per electron values are compared with the predictions of the encounter probability model of Sulik and Hock [16]. The theoretical curve has been calculated without correcting for the increased binding energy and using the effective charge of the projectile. The latter was determined from the binary encounter picture to be responsible for the L-shell ionization.

We conclude that excitation to higher shells plays a non-negligible role in multiple ionization processes involved in energetic heavy ion - atom collisions and its contribution decreases with increasing projectile charge at a fixed projectile speed.

The authors acknowledge the continuous interest and help of Professors G.N. Flerov and Yu.Ts. Oganessian in this study. Thanks are due to Mr J. Köblös for technical assistance and to the operating crew of the U-300 cyclotron.

Table 2

The experimental and theoretical

ionization and vacancy production probabilities per electron

Projectile	Ne^{3+}		Ar^{6+}		Ne^{20+}	
	exp.	theor.**	exp.	theor.*	exp.	theor.*
P^i_{2s}	0.12(1)	0.146	0.21(2)	0.207	0.27(2)	0.313
P^i_{2p}	0.15(1)	0.165	0.28(1)	0.311	0.38(2)	0.482
$P^i_{L_{xx}}$	0.14(1)	0.160	0.26(1)	0.285	0.35(1)	0.438
P^v_L	0.20(2)		0.35(5)		0.38(7)	
P^i_{2p}/P^i_{2s}	1.3(1)	1.13	1.3(1)	1.50	1.4(1)	1.54

* according to Sulik and Hock [16], without correcting for increased binding energy

**from our previous measurement - Kádár et al, [6], calculated from the total/diagram ratio, supposing binomial distribution

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Кадар И. и др. E7-85-656

Описание процессов многократной ионизации с использованием оже-спектров, измеренных в столкновениях Ne^{3+}, Ne^{10+}, Ar^{6+} (5,5 МэВ/а.е.м.) – Ne

Исследовались процессы многократной ионизации в процессах ион-атомных столкновений на тяжелых ионах, а именно Ne^{3+}, Ne^{10+}, Ar^{6+} (5,5 МэВ/а.е.м.) – Ne. С помощью электростатического спектрометра электронов наблюдался спектр оже-переходов. Определены вероятности ионизации на один электрон для L-оболочки и отдельно для 2s и 2p подоболочек неона. Обнаружена значительная разница между образованием вакансий и вероятностью ионизации на L-оболочке, что указывает на более заметное влияние возбуждений на более высокие оболочки в этих процессах. Обсуждение результатов проводится в рамках существующих теоретических моделей.

Работа выполнена в Лаборатории ядерных реакций ОИЯИ.

Препринт Объединенного института ядерных исследований. Дубна 1985

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Characterization of Multiple Ionization Processes by Means of Auger Spectra Measured in Ne^{3+}, Ne^{10+}, Ar^{6+} (5.5 MeV/u) – Ne Collisions

Ionization probabilities per electron for the L-shell and separately for the 2s and 2p subshells of neon in the 5.5 MeV/u Ne^{3+}, Ne^{10+}, and Ar^{6+} – Ne collisions were determined. Significant differences between the vacancy production and ionization probabilities in the L-shell have been found indicating the nonnegligibility of excitations to higher shells in these processes.

The investigation has been performed at the Laboratory of Nuclear Reactions, JINR.

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