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ELECTRON CAPTURE BY SLOW Ne^{8+} RECOIL IONS

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Abstract

High-charge-low-velocity neon recoil ions have been produced by impact of 1.4 MeV/amu uranium ions. Electron capture from surrounding neutral background atoms in subsequent collisions has been studied by observing the quenching of K α x-ray lines from metastable states. Capture-rate coefficients have been determined for the systems Ne^{8+} on He, Ne, Ar, CH₄, and Xe.

Electron-capture processes in collisions between highly charged ions and neutral atoms have received increasing interest in recent years. There already exists a great body of literature of both theoretical and experimental work concerning multiply charged ion-atom collisions at fairly high collision velocities. However, for the very low velocity regime there is a nearly complete lack of data (Grandall 1980) due to the technical difficulties in producing highly charged ions at low laboratory velocities.

Using slow target recoil ions produced by impact of swift very heavy ions offers the opportunity for studying charge exchange between neutral atoms and highly charged ions at ultimately low velocities (Beyer and Mann 1981). We started the investigation of such systems with the aid of Auger-electron and x-ray spectroscopy (Mann and Folkmann 1979, Beyer et al. 1979) by which information was obtained on (i) recoil-ion velocity, (ii) excited states distribution after charge exchange, (iii) exothermic energy defect in quasi-resonant charge exchange reactions, and (iv) total capture rates (Beyer et al. 1980, Folkmann et al. 1981, Mann et al. 1981). In the 28 charge-exchange systems studied so far where the collision velocity laid between 0.8 and $5 \times 10^6 \text{ cm s}^{-1}$ and the ionic charge between 4 and 10, one-electron capture was found to proceed in a highly selective way. The principal quantum number n_0 of the final

state populated predominantly was found to be in excellent agreement with the predictions of a simple classical model

$$n_0^2 \leq \frac{q^2}{2J_B [1 + (q-1)/(1+2q)^{1/2}]}$$
(1)

where q is the charge of the collector ion and J_B is the ionization potential of the neutral collision partner in atomic units. From that static model which does not contain any velocity dependence a geometrical cross section

$$\sigma = \pi R^2$$

with

$$R = \frac{q-1}{q^2/(2n_0^2) - J_B}$$
(2)

is obtained. From the quantisation of n_0 , i.e. using the largest integral value defined by equation (1), an oscillatory behaviour of the cross section as a function of both the charge q and the ionization potential J_B is predicted (compare also Ryuufuku et al. 1980). As we first focussed our attention to points (i) through (iii) mentioned above only a crude determination of capture rates was available.

In a recent measurement (Beyer et al. 1981) employing the photon-quenching method the capture rate for Ne^{8+} on Ne collisions was determined where the Ne^{8+} recoil ions were produced by impact of 3.6 MeV/amu krypton ions. Good agreement between experiment and the prediction of equation (2)

was found. We have repeated this experiment using a 1.4 MeV/amu uranium beam and have extended the measurement to other neutral species. The experimental procedure is similar to that described previously (Beyer et al. 1981).

The neon Ka satellites were measured in 1.4 MeV/amu uranium-neon gas-target collisions using a high-pressure gas cell and a RBAP-crystal spectrometer. In the pressure range between 6 and 130 mbar the dependence on target pressure and on target composition was studied employing two component gas targets containing neon and an admixture of helium, argon, methane, or xenon.

In the Ka satellite spectrum of neon bombarded by fast ions as heavy as uranium there are only two prominent lines. They are due to the transitions $1s2p^3P_1 + 1s^2$ and $1s2p^3P_1 + 1s^2$ in NeIX. Their relative intensities as a function of gas density may be expressed theoretically following the lines of our previous publication (Beyer et al. 1981) with slight changes for taking into account a two- instead of a one-component target.

The number density n_i of target atoms in the excited state i satisfies the differential equation

$$\frac{dn_i}{dt} = \sigma_i N_1 j - \frac{n_i}{\tau} - n_i (k_{c1} N_1 + k_{c2} N_2) \quad (3)$$

where N_1 is the density of the first gas component from which the recoil ions are studied and N_2 the density of the second admixed gas. σ_i is the cross section for excitation from the ground state to the excited state i , j is the flux of the primary beam and τ is the radiative lifetime of the excited state and k_{c1} and k_{c2} denote the capture-rate coefficients for electron capture from the two different gas components, respectively.

The last term of equation (3) takes into account the collisional depopulation of the excited recoil ion in a secondary collision. As charge exchange has by far the largest cross section destroying the excited state i other depopulation processes can be neglected. In our experiments where the observation time is large n_i is at equilibrium and the number of photons emitted per unit time and volume simply reads

$$n_i \tau^{-1} = \frac{\sigma_i N_1 j}{1 + \tau (k_{c1} N_1 + k_{c2} N_2)} \quad (4)$$

The singlet/triplet intensity ratio for our application then can be expressed as

$$\frac{I(^1P)}{I(^3P)} = \frac{\sigma(^1P)}{\sigma(^3P)} [1 + \tau(^3P) (k_{c1} N_1 + k_{c2} N_2)] \quad (5)$$

noting that $\tau(^1P) (k_{c1} N_1 + k_{c2} N_2) \ll 1$ because of the small lifetime of 10^{-13} s of the singlet state (Lin et al. 1977).

Equation (5) predicts a I_p/I intensity ratio which is linear in the partial pressures. Our experimental data are consistent with such a linear pressure dependence obtaining reasonable linear least squares fits. From the slopes of those fits the capture-rate coefficients can be obtained taking into account the lifetime of $^{21}P_1 = 0.18$ ns (Lin et al. 1977, Tunnell et al. 1980). In case of the mixed target gases the neon partial pressure was held constant to 27 mbar whereas the partial pressure of the admixed gas was varied. As an example figure 1 demonstrates the pressure dependence in case of pure neon and for neon-helium and neon-xenon mixtures. The straight lines are the linear least squares fits to the experimental data points. In case of helium the slope is much lower and in case of xenon it is much higher than in the pure neon case indicating a lower and a higher capture rate, respectively. A few additional runs were made by keeping the partial-pressure ratio 1:1 and varying the total pressure. Those cross checks confirmed the results obtained with the procedure mentioned above within the experimental accuracy. For the total capture rates we claim an experimental error of $\pm 30\%$ & mainly due to the error in the absolute gas pressure and in the relative line intensities. The extracted capture rates are listed in table 1. For the mean recoil velocity we adopt the value of $v_{rec} = 0.8 \cdot 10^6$ cm s⁻¹ determined for Ne⁷⁺ recoil ions from an independent measurement (Mann et al. 1981, Mann et al. to be published). The neon data of

both experiments using the 1.4 MeV/amu uranium and the 3.6 MeV/amu krypton beam agree within the experimental accuracy.

The capture cross sections $\sigma_c = k_c/v_{rec}$ are shown in figure 2 as a function of the ionization potential I_B . Included in the figure is the geometrical cross section as determined from equation (2). Despite the crude theoretical treatment agreement is to some extent satisfactory. An experimental confirmation of the oscillations of the capture cross section as function of the ionization potential is not yet clear. More elaborate theoretical approaches should be applied to the very low velocity regime studied here.

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Table 1 : Experimental capture rates for $\text{Ne}^{8+} + \text{B}$,
 $v_{\text{rec}} = 0.8 \cdot 10^6 \text{ cm s}^{-1}$

Gas B	Ionization Potential/au	Capture Rate $k_C/10^{-9} \text{ cm}^3 \text{ s}^{-1}$
He	0.900	1.0 ± 0.3
Ne	0.792	2.9 ± 0.9
Ar	0.579	8.2 ± 2.5
CH ₄	0.463	8.0 ± 2.4
Xe	0.446	23 ± 7

Figure Captions

Figure 1 Pressure dependence of the $1s2p\ ^1P/{}^3P$ intensity ratio in Ne IX for different target composition. In case of the mixed gases the neon partial pressure amounts to 27 mbar.

Figure 2 Experimental charge-exchange cross sections for Ne^{8+} recoil ions on various neutrals. The solid line represents the geometrical cross section as given by equation (2).

Figure 2