FORMATION OF EXCITED STATES IN COLLISION BETWEEN CARBON IONS AND ARGON ATOMS AT INTERMEDIATE VELOCITY

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LRAP - 112 (1990)

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1. INTRODUCTION

The formation of excited product states is one of the prominent features of charge exchanging processes between atoms and ions. The aim in this work is to give a brief introduction to some aspects of atom collisions and to describe an experiment, which is made as a test of the equipment at Lund for beam-gas experiments.

In this present work, emitted light has been measured from the collision system

$$C^{q+} + Ar \rightarrow C^{(q-i)+} + Ar^{j+} + (j-i)e^{-} \qquad (1)$$

at approximatly 2 MeV, 150 keV/amu. The charge q ranged from 2 to 4 and the emitted light in the wavelenght interval 950 to 1700 Å was recorded.

The interpretation of the experimental work presented here is mainly based on semiclassical arguments and scaling relations, presented in secton 2.1 and 2.5, rather then on more extensive calculations, briefly introduced in the sections 2.2-2.4. Section 3 covers the experiment, 3.3 presents the results. Finally section 4 is a short summary.

Atomic units are used throughout unless explicitly indicated otherwise.

2. THEORY / BACKGROUND

2.1 BASIC COLLISION THEORY

In order to describe the process when an ion collides with an atom according to

$$A^{q+} + B \rightarrow A^{(q-i)+} + B^{j+} + (j-i)e^{-} \qquad (2)$$

one should begin by considering the possible final states. There are three different types of processes that can occur:

i) Elastic collision, $i=j=0$, the ion and the atom are scattered without change in their internal energy.

ii) Inelastic collision, $i=j=0$, one or two of the colliding partners undergo a change in their internal energy during the process.

iii) Reaction, i and/or j differ from zero, and the system splits into two or more particles, different from $(A^{q+}+B)$.

A channel is, by definition, a possible mode of fragmentation of the composite system $(A^{q+}+B)$. A channel is open if the corresponding process is allowed by known conservation laws, otherwise it is said to be closed. If a collision is elastic the colliding partners remain in their initial channel. Inelastic collisions and reactions are leading from a given initial channel to a different final channel.

In general any process shall obey the law of energy conservation. Energy may be converted from kinetic to internal, or vice versa, during a collision. This change in internal energy, for the colliding particles, is within the framework of this discussion, equivalent with electron rearrangment. From classical arguments is it possible to determine an upper limit for the change in internal energy [1].

This applied to a collision system of a 2 Mev Carbon beam incident on an Argon atom at rest, gives a result that is very large compared to the binding energy of any single electron in the colliding system. This implies that from the energy conservation point of view almost any rearrangement of the electrons is possible.

Processes where the change in internal energy is large are associated with small cross sections, since they demand that the two nuclei are close to each other and interact heavily.

A crude estimate for a typical change in internal energy can be found from comparison with beam foil spectroscopy. When a 2 MeV carbon beam passes through a thin carbon foil, it looses 0,2-2 % of its kinetic energy. 4 keV, 0,2 %, is still a large amount of energy compared to the energy levels of neutral and low ionized Carbon and Argon.

Momentum must also be preserved in a collision. A simple model of a colliding system is to regard the colliding system as 3 particles; an ion, an atom core and one active electron. The electron is initially orbiting the atom core. In a collision the electron can be captured by the ion or be scattered away from the atom core to become a free electron.

Momentum preservation then resticts the possible final states. To describe a many electron collision system a model with more active electrons is needed. For a model that contain more than three particles, the restrictions imposed by momentum conservation is less useful, since there are many different combinations that fulfill the momentum preservation criteria.

From a macroscopic point of view an angular momentum is introduced as the product between the projectile velocity and the distance between the projectile and the target electron. Using correspondence principle arguments this can be used to determine an approximate l quantum number for the process.

The next step, assuming that the main final states are known, is to calculate the cross sections for the different final channels.

2.2 CALCULATIONS

The process is defined by the time dependent Schrödinger equation

$$H\Psi = i\partial\Psi/\partial t \qquad (3)$$

where the first problem is to choose a Hamiltonian and wavefunction, that covers all aspects of the collision. The Hamiltonian shall describe the motion of the particles in the collision system and all the interaction between them. For collision systems with kinetic energies above 500 eV/amu one usually adopts the semiclassical approximation that the two nuclei moves by a classical straight line trajectory, $R = R(t) = \mathbf{b} + \mathbf{v}t$; $\mathbf{bv} = 0$ [2].

The demands on the wavefunction are that it shall describe the system at all times, before during and after the collision. This means that it must be able to describe the separated incident particles, the system consisting of two strongly interacting colliding partners close to each other and at last the outgoing particles, that can be different than the incident ones.

When introducing approximations it is convinient to distinguish between three different cases; one, two and many electrons. Here one, two and many respectively stand for the number of active electrons in the colliding system. Each one of these approximations can then be further divided with respect to velocity region, low $v \ll v_0$, intermediate $v \approx v_0$ and high $v \gg v_0$, where v_0 is the orbital velocity of the active electron, form the Bohr model point of wiev. From here on a restriction to the intermediate velocity region, $v \approx v_0$, will be made.

2.3 ONE ELECTRON APPROXIMATION.

Within this approximation one considers one electron as active, and moving in the effective field of the atomic core and the ion. The hydrogen atom and a fully stripped ion system then provide a perfect case for theoretical work, because then there are no problems with electron structure.

The hamiltonian for a one electron two nuclei, of charge Z_1 and Z_2, system is [2]

$$H = T - r_1^{-1} \cdot Z_1 - r_2^{-1} \cdot Z_2 + R^{-1} \cdot Z_1 Z_2 \qquad (4)$$

in the center of mass system. T is the kinetic energy operator and the different coordinates given in figure 1.

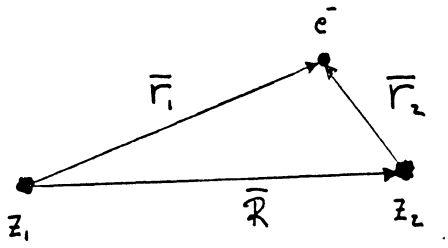

figure 1. The coordinate vectors for hamiltonian (4)

The general approach to get a wavefunction is by expansion. Starting with choosing a set of linearly independent basis functions $\psi_j(\mathbf{r},\mathbf{R})$ an approximation to the wavefunction Ψ the finite expansion [2].

$$\Psi(\mathbf{r},\mathbf{R}) = \sum a_j(t)\psi_j(\mathbf{r},\mathbf{R}) \qquad (5)$$

One way to choose a set of basis functions is to use two subsets of travelling atomic orbitals (ψ^A) and (ψ^B) which asymptotically, $|t| \to \infty$, describe all target and projectile states respectively [2]

$$|t| \to \infty;\ \psi_j \to \psi_j^A\ 1 \le j \le L \text{ or } \psi_j^B\ L < j \le N \qquad (6)$$

then one has a general expansion expression [3]

$$\Psi(\mathbf{r},\mathbf{R}) = \sum c_m(t)\psi_m^A(\mathbf{r},\mathbf{R}) + \sum b_n(t)\psi_n^B(\mathbf{r},\mathbf{R}) \qquad (7)$$

If this expression is used in the time dependent Schrödinger equation (3), projected to different final channels ψ^A_i and ψ^B_i we get a system of coupled equations

$$\begin{aligned} & i(\partial c_i(t)/\partial t + \sum \partial b_n(t)/\partial t \langle \psi_i^A | \psi_n^B \rangle) = \\ & = \sum c_m(t) \langle \psi_i^A | H - i\partial/\partial t | \psi_m^A \rangle + \\ & + \sum b_n(t) \langle \psi_i^A | H - i\partial/\partial t | \psi_n^B \rangle \end{aligned} \qquad (8)$$

$$\begin{aligned} & i(\sum \partial c_m(t)/\partial t \langle \psi_i^B | \psi_m^A \rangle + \partial b_i(t)/\partial t) = \\ & = \sum c_m(t) \langle \psi_i^B | H - i\partial/\partial t | \psi_m^A \rangle + \\ & + \sum b_n(t) \langle \psi_i^B | H - i\partial/\partial t | \psi_n^B \rangle \end{aligned} \qquad (9)$$

which defines the coefficients c(t) and b(t). The two center basis (6) can be improved by the addition of further functions, centered on nuclei 1 and 2, which are not solutions to an unperturbed atomic Schrödinger equation, but of a more general nature. To simplify the calculations it is convenient to choose these pseudo-states to be orthogonal to the atomic orbitals. The original atomic orbitals then describe the entrance and exit channels while the introduced pseudo functions simulate the molecular feature when the two atoms are close. There are two different motives for the addition of extra functions. At low velocities it is of great importance to represent the united atom, formed during the collision. For instance studying the $H^+ + H$ system,

Cheshire et. al. [4], added pseudo states, chosen to overlap the orbitals of the united atom ,He^+, as much as possible. The second main reason lies in the increasing importance of ionization as the velocity, v, increases. Since it is difficult to bring in continuum wave to the expansion, the continuum can be approximated with a discrete set of functions, which are chosen to overlap the continuum wave functions as closely as possible. In theory one can specify two special cases, *i*)electron capture and *ii*)target ionization. In an experiment both processes occur together.

i)Electron capture. To describe a process according to

$$A(n_0,l_0,m_0)+B^{q+} \rightarrow A^+ + B^{(q-1)+}(n,l,m) \qquad (10)$$

there are three slightly different ways to go. Besides the semiclassical close coupled method there are a approximated close coupled method and a classical trajectory Monte Carlo method.

Close coupling. The calculation starts from defining the atomic orbital basis, that is capable of describing both the two separated atoms and pseudo state that appears when the two atoms are close to each other. The way to create this basis is briefly discussed by Fritsch and Lin [5], who have also performed a rather extensive calculation on different Z+H system [6], Z:Be^{4+}, B^{5+}, C^{6+}, N^{7+}, O^{8+}, for low to intermediate velocity. Using the same method Tawara and Fritsch present data on C^{4+},O^{4+} and O^{5+} colliding with atomic hydrogen [7].

Approximative close coupling. The treatment of coupled channel equations becomes significantly simplified, if all coupling except the direct one between the initial and final channel is neglected. The probability for a particular transition is then expressed in terms of separated two state transition probabilities.

Two approaches along this line have been made, a multi channel version of the Vainstain-Presnyakov-Sobel'man approximation, M-VPS,[3] and a Unitarized Distorted Wave Approximation, UDWA, [3]. These have proven to be appropriate for highly charged ion atom system. The UDWA theory applied to calculate partial cross sections, for a $Si^{14+}+H$ system at 100 keV/amu [8] show a broad n-distribution around a peak at $n_{max}=9$. n_{max} is though strongly velocity dependent for $v>2$ [9].

Classical Trajectory Monte Carlo. The CTMC method is a technique in which a large ensemble of projectile target configurations is sampled, in order to simulate the two colliding particles. The MC nature of the process consists of choosing initial configurations the ensemble properties of which, reproduce the quantum mechanical orbital electron momentum distribution. The classical trajectories are then found by iterativly solving the Hamilton equations of motion. This method is described by Olson [10] whereas charge transfer data are presented by Olson and Schultz [11] for C^{6+} and O^{8+}. The distribution of final states, from electron capture, for a general $B^{q+}+H$ colliding system shows the following features, when the CTMC method is used to calculate partial cross sections[9]. The n distribution has anti symmetric shape, around a maximum at $n_{max}\approx q^{3/4}$. Levels with $n<n_{max}$ are less populated than those with $n>n_{max}$. With increasing velocity and charge the distribution gets broader and more anti symmetric. The l-distribution also shows an n dependence, for $n<n_{max}$ the l-population is biased towards large l-values and exceeds the statistical weight. For the opposite area with $n>n_{max}$ the l-distribution has a maximum at $l\approx n_m$, beyond which the population is less than the corresponding statistical value.

ii)Target excitation and ionization. In the intermediate velocity region these two processes become competitive with electron capture. The adequate way to describe these phenomena is again the close coupled method , but with another set of atomic state functions, in the expansion (5). The direct numerical solution of the corresponding system of equations is of course difficult, so instead one uses different approximations. For a brief introduction see reference [12]. The ionization process is somewhat more delicate than excitation because of the problem to incorporate the wavefunction for the continuum state, in the wavefunction expansion. In reference [13], Rivarola et. al. calculate total cross sections, for single electron ionization of target, at intermediate to high velocities. The collision systems were C^{q+} (q=4,5,6) or O^{q+} (q=6,7,8) ions incident on atomic hydrogen and C^{6+} or O^{q+} (q=6,7,8) ions incident on helium atoms. The theoretical model used was a Continuum Distorted Wave Eikonal Initial State Approximation [14]. In this model distorsion is accounted for in the entrance channel via the eikonal approximation and in the exit channel via the continuum distorted wave approximation. This method appears to give qualitative agreement with with experimental data but quantitative off up to a factor 3.

2.4 TWO / MANY ELECTRON PROCESSES.

Processes that involve transitions of more than one electron are much more complex to describe. This is due to the fact that correlation effects play a role in the dynamics of these events. Description of correlation is in itself a difficult theoretical problem. The existence of, at least, two active electrons in the system makes the variety of possible collision processes very broad, compared to a single electron system. The electrons can make transitions both simultaneously and/or consecutively, during one collision. The basic two electron capture can take place both ways

$$A+B^{q+}->A^{2+}+B^{(q-2)+} \qquad (11)$$

and

$$A+B^{q+}->A^{1+}+B^{(q-1)+}->A^{2+}+B^{(q-2)+} \qquad (12)$$

In analogy with this simultaneous excitation and capture can occur in, at least, two different ways

$$A+B^{q+}->A^{+*}+B^{(q-1)+} \qquad (13)$$

and

$$A+B^{q+}->A^{*}+B^{q+}->A^{+*}+B^{(q-1)+} \qquad (14)$$

The effect is that it is much more difficult to make theoretical calculations. Dansgard et. al. [18] measured partial cross sections, using coincidence time of flight technique. The following five processes were individually specified.

$$Au^{q+} + He \rightarrow Au^{q+} + He^{+} + e^{-} \quad (15)$$

$$Au^{q+} + He \rightarrow Au^{q+} + He^{2+} + 2e^{-} \quad (16)$$

$$Au^{q+} + He \rightarrow Au^{(q-1)+} + He^{+} \quad (17)$$

$$Au^{q+} + He \rightarrow Au^{(q-1)+} + He^{2+} + e^{-} \quad (18)$$

$$Au^{q+} + He \rightarrow Au^{(q-2)+} + He^{2+} \quad (19)$$

The measurement was performed at an energy of 20 MeV, 100 keV/amu, and with q ranging in the interval from 5 to 21. The result, figure 2, shows that at low q,

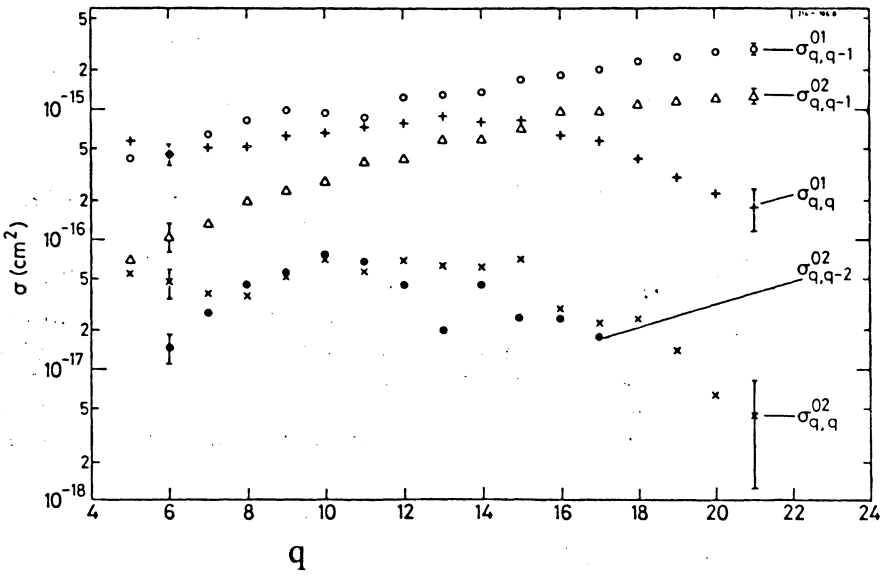

figure 2. Partial cross sections versus charge q, for 20 MeV Au^{q+} + He, sub/super script indicate beam/target charge before,after collision. From [18]

capture (17) and ionization (15) are dominating mechanisms, with camparable magnitude. Increasing q, capture/ionization (18) increases and contributes significantly while pure ionization (15) decreases. Comparing the two pure electron capture processes gives that while single electron capture increases doubly electron capture decreases with q. The two pure ionization processes follows approximately each other in behavior.

2.5 SCALING LAWS.

In many cases, a reasonable approach is to use scaling laws, instead of extensive calculations. The problem is to establish dependencies that are valid over a broad range of collision parameters. Janev and Hvelplund [15] try to give a systematic analysis of different earlier proposed scaling laws, for single electron capture and ionization. Their general interest was the scaling of cross sections with q.

Electron capture. Scaling with q can be performed on the basis of the classical model for the process as well as the atomic state based close coupling method. For $v \leq 1$, electron capture can take place via an overbarrier transition, since for internuclear distances $R \leq R_c \simeq (2q)^{1/2}/I_0$, the barrier separating the atomic and ion potential wells becomes lower than the energy level for the outer electron in the target atom. The cross section is thus given by

$$\sigma = \pi R_c^2 \simeq 2\pi q/I_0^2 \qquad (20)$$

This gives a linear q dependence and scales like I_0^{-2}. For $v \geq 1$, applying the CTMC method to the $B^{q+} + H$ system, there has been found a linear q dependence and a weak velocity dependence. Within the atomic state based quantal calculations the M-VPS approach gives a linear q dependence for σ, in the $v \leq 1$ region. For $v \geq 1$ the UDWA approximation yields a $q^{1,07}$ dependence of σ. For higher velocities $v > 1$ the situation becomes moore complex and depends also on the structure of the target atom. The problem is that for multielectron targets, electron capture from inner shells becomes possible with increasing velocity. According to the classical Bohr Lindhard model [16] σ scales like I_0^{-2} for $v < Z^{1/2}q^{1/4}$, where σ is linealy dependent on q. In the opposite velocity region the cross section scales like $I_0^{3/2}$ and has a q^3/v^7 dependence. To represent these data in a unified form it is convinient to use the reduced

parameters $\sigma' = \sigma/q$, $v' = v/q^{1/4}$ and $E' = E/q^{1/2}$.

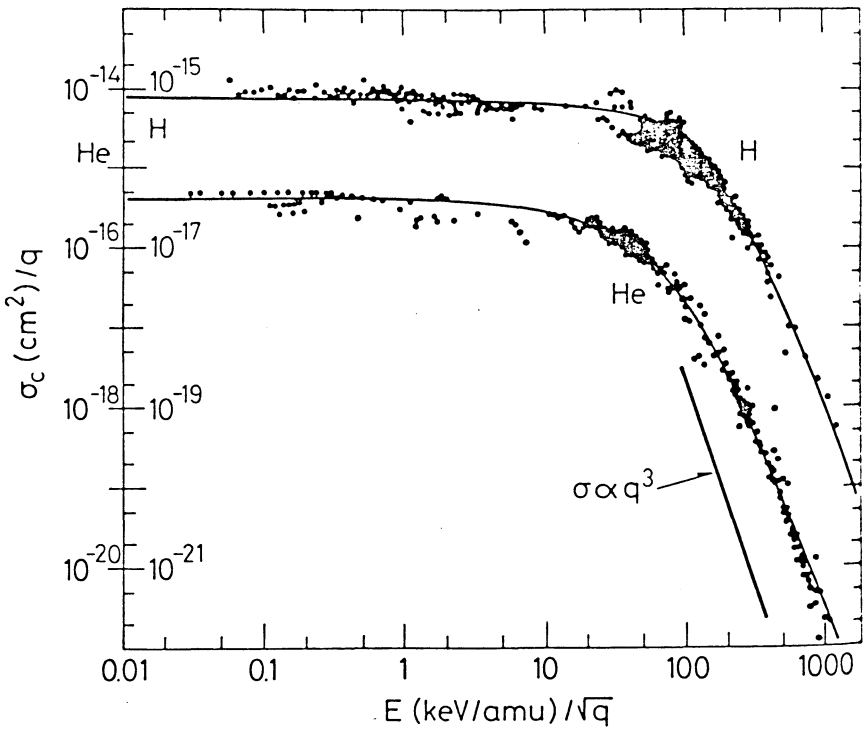

figure 3. Reduced electron capture cross sections versus reduced energy, for hydrogen and helium targets. Solid lines are fits to experimental data. From [15].

Target Ionization Ionization processes are much less investigated than electron capture, so far. But the direct ionization process

$$A + B^{q+} \rightarrow A^{+} + B^{q+} + e^{-} \qquad (21)$$

where the target atom A has the initial binding energy I_0, two scaling relationships have been proposed. According to the classical Bohr model of ionization [17], the cross section scales like $I_0^{-3/2}$ in the region $E(keV/amu) \leq 25qI_0^{-1/2}$, and has a linear q dependence. In the opposite region it is dependent of q^2 and scales like $I_0^{-1}\ln(I_0^{-1})$. The reduced representation for σ is the same as for electron capture,

but for energy the reduced parameter $E' = E/q$ is used.

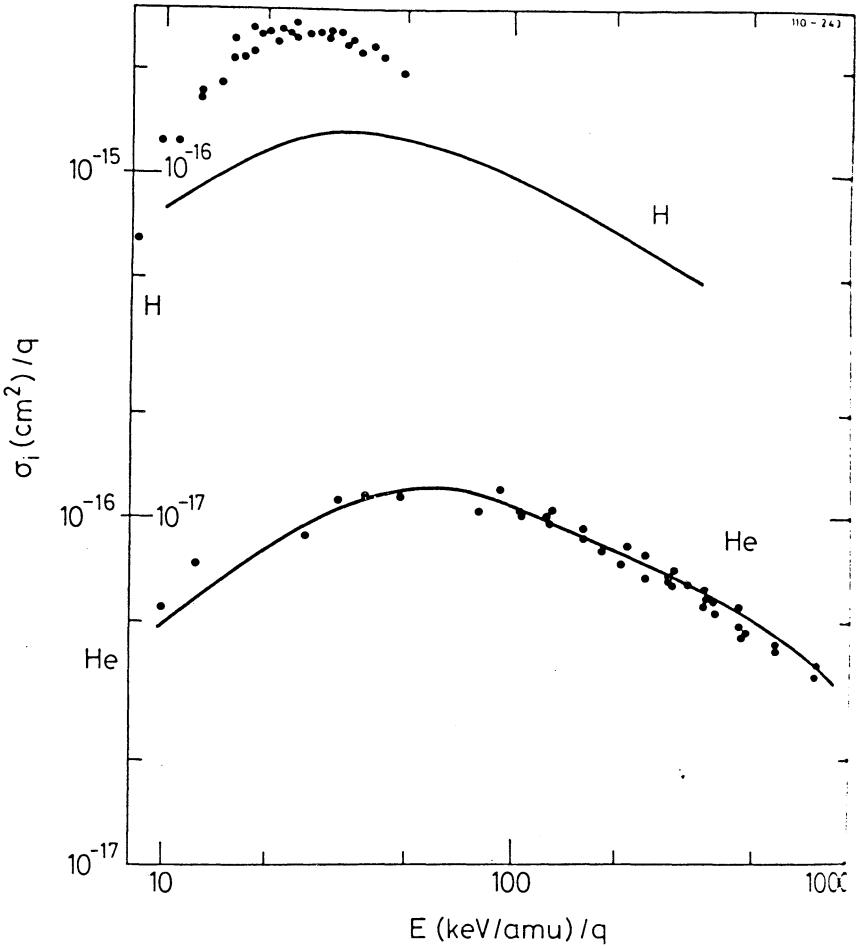

figure 4. Reduced ionization cross sections versus reduced energy, for hydrogen and helium targets. Solid lines are scaling relations, dots experimental data. From [15]

2.6 EXPERIMENTAL METHODS

To observe ion atom collision processes, first one have to create the collision. One usual way of doing this is to have a beam of ions incident on a target.

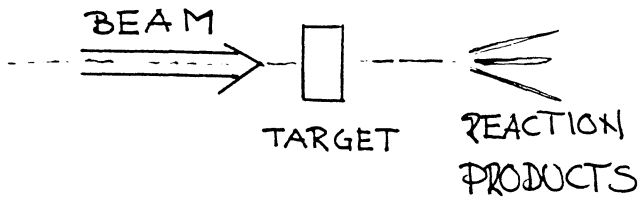

figure 5. A schematic picture of a collision experiment

Figure 5 shows a schematic picture of a collision experiment. When the ion beam passes through the target the ions and atoms may interact individually and the reaction products are formed. The ones considered here are; atoms, ions, electrons and photons. Basically these particles can be divided into two classes, primary and secondary, depending on wheater they are created during the primary reaction or in subsequent process. For instance if an excited ion is created in the collision and deexcited by photon emission, the excited ion is a primary particle and the photon is a secondary.

Translational Energy Spectroscopy, TES, is a usual method to detect primary particles. It is based on the law of energy conservation mentioned earlier. By measuring the distribution of kinetic energy after the collision and comparing it with the initial energy, one can determine the energy gain/loss for the process. The energy gain/loss is equivalent to the change in internal energy for the colliding particles. From this data it is possible identify different states produced in the

collision. At intermediate energies the energy gain/loss method is less satisfactory [8] because the relative change in energy for the ion is small.

On the other hand, to detect secondary particles the fact that many of the states formed after a collision process are excited is used. By studying their decay it is possible to identify the states primairily created in the collision process. The major drawback with this is that one observes the decay process and not the creation process itself. Depending of which excited states there are, there are two conventional methods to use, Photon and Electron emission spectroscopy.

Photon Emission Spectroscopy, is a powerful technique to investigate excited atomic states because of its high wavelenght resolution and that it is possible to identify specific quantum numbers for a transition. There are however some drawbacks, because of the small sensitivity in photon detection, with grating monocromators there have to be up to 10^6 actual photons for 1 detected photon.

Electron Emission Spectroscopy. Ion atom collision can also lead to electron emission, via varios reaction channels. Since the different emission mechanisms give the emitted electron a characteristic energy, one can via measurement of the energy distribution identify the different states. A particular useful way to observe electron emission, for ion atom collision experiments using fast beams, is electron spectroscopy in the forward or backward scattering direction [3]. This method gives the possibility to observe low energy Auger electrons.

For a thorough rewiev of experimental methods see Ref [3] and the references therein. Ref [19] and the references therein cover both the experimental technique for electron spectroscopy and briefly the theory of non radiative transitions.

3. EXPERIMENT

3.1 EXPERIMENTAL SET UP

The experiment was made at the Pelletron tandem accelerator, at the University of Lund. To obtain an ion beam consisting of different charge states with the same kinetic energy, a "stripper" foil between the accelerator and the analyzing magnet was used. This arrangement gives the possibility to choose one of the charge states present in the beam, by tuning the magnetic field in the analyzing magnet. The target gas is injected by an ordinary plastic hose, with a part of a micro channel plate attached to its opening. This arrangement gives a well localised gas jet. [20] Optical emission from the target area was recorded with an Minuteman 1-meter normal incidence monochromator. A grating with 1200 lines/mm was used in combination with a channeltron detector. To compensate for the doppler broadening of the peaks caused by the moving light source the monochromator was refocused.[21]

3.2 TRANSITION IDENTIFICATION

The identification was performed in three steps. First preliminary peak positions were obtained by an automatic peak finding routine.[22] This is a computer program that identifies peaks, by studying the first and second derivatives of the measured spectra. Secondly some of the blended/unresolved structures were decomposed into Gaussian shaped lines, using the computer program CARATE. [23] This is a program that uses a non linear least square fitting technique and needs direct manual guidelines. Finally the peak positions were converted into wavelength through a polynomial of first degree, with the use of known lines as references.

3.3 RESULT

The experimental work was divided into three parts, one for every charge state of the incident Carbon ion.

Table I C^{2+} incident on Ar at 1,83 MeV

inten-sity	wavelength (Å)		transition
	obs.	teor.[a]	config.
149	1324,0	1323,9331[b]	CII $2s2p^2$-$2p^3$
367	1335,5	1335,3129[b]	CII $2s^22p$-$2s2p^2$
79	1343,5		
44	1358,4		
35	1366,3		
61	1378,6		
51	1400,7		
32	1419,3		
71	1428,2		
35	1432,3		
34	1435,7		
110	1447,0	723,3605[d]	ArII $3p^5$-$3p^4(^3P)4s$
87	1451,0	725,5485[d]	ArII $3p^5$-$3p^4(^3P)4s$
34	1461,7	730,9297[d]	ArII $3p^5$-$3p^4(^3P)4s$
38	1480,6		
50	1490,4		
36	1541,6		
33	1544,7		
144	1561,1	1561,0546[b]	CI $2s^22p^2$-$2s2p^3$
33	1569,5		

a: Theoretical value from [24]. b: Unresolved structure, theoretical value weighted by LS intensities. d: Second order wavelength.

i) C^{2+} incident on Ar at 1,83 MeV. In this part, see Table I for wavelenght list and figure 6 for the obtained spectrum, fourteen lines was left without identification. The six identified transitions indicates that the following tre processes occurred in the collision. 1) Two electron capture and simultaneous excitation, $2s^22p^2$ - $2s2p^3$ transition in CI. 2) Single electron capture and excitation, $2s2p^2$-$2p^3$ and $2s^22p$-$2s2p^2$ transitions in CII and 3) single target ionization and excitation, $3s^23p^5$-$3s^23p^4(^3P)4s$ transition in Ar II.

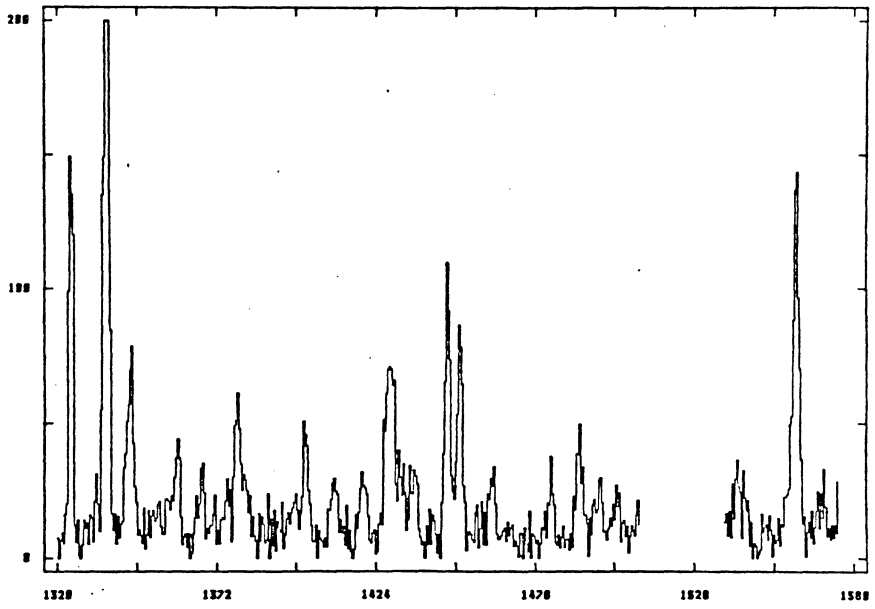

figure 6. Obtained spectrum, taken at 1,83 MeV C^{2+}

ii) C^{3+} incident on Ar at 2,05 MeV. The identified, Table II and figure 7, transitions indicates that the result of the ion atom collision were the five following. 1) three electron capture and simultaneous excitation, $2s^22p^2$ - $2s2p^3$ transition in CI, 2) two electron capture and excitation, $2s2p^2$-$2p^3$ and $2s^22p$-$2s2p^2$ transitions in CII, 3) single electron capture, $2s^2$-2s2p transition in CIII, 4) projectile excitation, $1s^22s$-$1s^22p$ transition in C IV and 5) target excitation, $3p^6$-$3p^5(^2P_2)4s$ transition in ArI.

Table II C^{3+} incident on Ar at 2,05 MeV

inten-sity	wavelength (Å)		transition
	obs.	teor.[a]	config.
11	975,3[c]		
24	977,3[c]	977.020	CIII $2s^2$-2s2p
78	1048,0	1048,2199	ArI $3p^6$-$3p^5(^2P_2)4s$
66	1067,8		
35	1324,1	1323,9331[b]	CII $2s2p^2$-$2p^3$
124	1335,7	1335,3129[b]	CII $2s^22p$-$2s2p^2$
240	1547,9[c]	1548,202	CIV $1s^22s$-$1s^22p$
119	1550,5[c]	1550,774	CIV $1s^22s$-$1s^22p$
38	1561,2	1561,0546[b]	CI $2s^22p^2$-$2s2p^3$
51	1592,2		

a: Theoretical value from [24]. b: Unresolved structure, theoretical value weighted by LS intensities. c: Structure resolved by CARATE [23].

iii) C^{4+} incident on Ar at 2,05 MeV. The result from the measurement,C^{4+} incident on Ar at 2,05 MeV, was not analyzable, it was not possible to distinct the lines from the noise.

Out of a total of thirty lines thirteen transitions were identified. There were three circumstances that both decreased the number of detected lines and made the transition identification difficult. These were *i*) the low beam current in the target chamber, *ii*) the high background noise level and *iii*) the fact that the recorded spectral region were rather narrow. The first decreases the probability for any process and the second demands that the intensity of a line had to high to be observed above the background.

Without proper cascade analysis, it is impossible to determine if the upper levels of the identified transitions were directly populated in the collision process or if they are steps in a cascade chain.

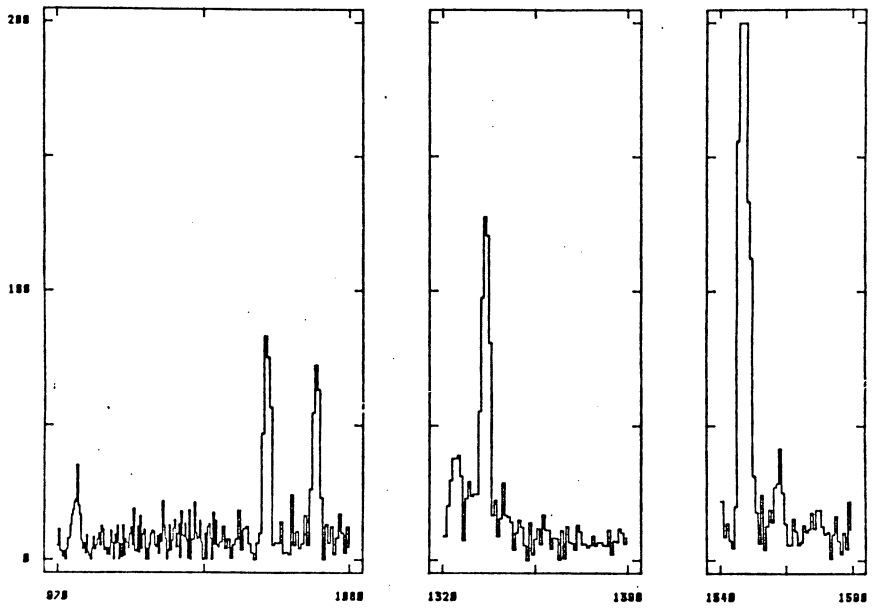

figure 7. Obtained spectrum, taken at 2,05 MeV C^{3+}

4 SUMMARY

There is no theoretical model that is fully capable of explaining many electron system collision processes. If a restriction to single electron system is made the situation is better. For different cases there are different methods to use.

To summarize the experimental work the results are encouraging but insufficient. It is difficult to make any definite conclusions. The observed resonance lines in different charge states indicates:

A) C^{2+} as incident particle: Target ionization and both 1 and 2 electrons captured by the projectile.

B) C^{3+} as incident particle: Target excitation and 1,2 and even 3 electrons captured by the Carbon ion.

The question of single collision conditions have to be left unanswered at the moment. Further experimental work have to be done to validate the results.

To continue with this type of experiments there are two major problems that have to bee taken care of. The first is to increase the beam current in the target chamber. Secondly the gas injection has to be developed further, since a well localized and well defined gas jet is required as a target.

ACKNNOWLEDGEMENTS

I would like to thank:

My supervisor Sven Huldt for his inspirational way of sharing some of his knowledge with me.

Crister Jupen, Magnus Westerlind, Andreas Redfors and Peter Bengtsson for there work with the experiment.

Indrek Martinsson both for fruitful comments on this text and for his advise with references.

Everybody at the departement of atomic spectroscopy, for their patience with my questions, especially Lars Engström and Ulf Litzen who, besides Sven, got a lions share.

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