Vector Polarisation Analysis for Quasi-Two-Electron Systems: Mg\(^0\)-Inert Gas Collisions

W. Heydenreich, B. Menner, L. Zehnle, and V. Kempter
Fakultät für Physik der Universität, Freiburg i.Br.,
Federal Republic of Germany

Received January 28, 1983; revised version April 8, 1983

Results of photon-scattered atom coincidence measurements are presented for Mg-inert gas collisions. A polarisation analysis of the collision induced Mg(3\(^1\)P-3\(^1\)S) photons emitted perpendicular to the scattering plane was carried out at 1 keV collision energy as a function of the impact parameter. From these data the quantum-mechanical scattering amplitudes for the excitation of one of the two available Mg 3s-valence electrons are derived. The results are compared with the corresponding ones for the Mg\(^+\)-inert gas collisions. A good qualitative understanding of the mechanism can be obtained.

1. Introduction

Mechanisms for the excitation of the loosely bound valence electron of the so called quasi-one-electron systems are by now relatively well understood [1]. Basically, two mechanisms have been found, and are now also born out by model calculations [2, 3].

Mechanism (i): In violent collisions the two cores interpenetrate considerably. Excitation takes place because the molecular orbitals of the collision pair strongly interact in this region of internuclear distances. The excitation probability strongly depends on impact parameter \(b\).

Mechanism (ii): For soft collisions at large impact parameters only the interaction between the valence electron and the inert gas core is important while the core-core interaction may be neglected. The time-dependent perturbation of the valence electron by the passing inert gas charge cloud then induces excitation which is only weakly depending on impact parameter and extends to much larger impact parameters.

So far the only studies on two-electron systems which consist out of two loosely bound electrons outside two closed shells were carried out for alkali-alkali [4, 5] alkaline earth-inert gas [5], and Al\(^+\)-inert gas collisions [6]. These studies have furnished the energy dependence of the integral cross sections for valence electron excitation [4, 5] or have presented differential cross sections for the most prominent inelastic processes [6]. The results suggest that for these systems the same mechanisms (i) and (ii) are important as for the quasi-one-electron systems.

The optimal experimental information required to test predictions concerning excitation mechanisms are the quantum mechanical scattering amplitudes for the excitation of one or both of the valence electrons in such systems as a function of impact parameter and/or collision energy. This knowledge then allows for the most direct comparison between theory and experiment without any averaging procedures to the output of the calculations.

We present such information for the Mg(3\(^1\)P)-state excited in Mg\(^0\)-inert gas collisions at 1 keV collision energy. In the present case the information has been obtained by performing a polarisation analysis on such photons which are emitted in collision events with planar symmetry.

There are several reasons for our choice of the Mg\(^0\)-inert gas systems:

1. The Mg(3\(^1\)P-3\(^1\)S) transition (2,852 Å) is in the spectral region still accessible to polarisation analysis.
2. There are no spin variables (as long as the inert gas atom remains in its ground state) which would tend to average out polarisation effects [7].
3. The energy dependence of the integral excitation cross sections and of the polarisation fraction is already available [5].
The studied excited state Mg\(^{3\,P}\) is well separated from the next higher excited states; we can therefore hope to describe the excitation process by including only a few channels into a close-coupling calculation \([8]\).

Detailed experimental information is available for the Mg\(^{+\,3\,P}\) excitation in the quasi-one-electron Mg\(^{+}\)-inert gas collision systems \([9-11]\).

### 2. Experimental

Most parts of the apparatus have been described at several occasions (see for instance \([7]\)). The atomic beam was produced by neutralising a Mg\(^{+}\) beam through resonant charge transfer. The metastable content of the 1 keV Mg\(^{0}\) beam produced in this manner is small (<1\% \([5]\)).

The neutral Mg beam impinges upon an inert-gas target under single collision conditions. A certain fraction of the projectiles is excited to the 3\,\(1P\) state. The inelastic process is identified by determining the time correlation between the Mg(3\,\(1P\)--3\,\(1S\)) photon emission and the resulting Mg(3\,\(1S\)) atom scattered into the angle \(\theta\). For each value \(\theta\) the polarisation vector \(\mathbf{P} = (P_1, P_2, P_3)\) is derived by performing the polarisation analysis of the coincident photons emitted perpendicular to the scattering plane.

An angular range of about 20 degrees of the angular distribution of the scattered Mg atoms is detected simultaneously by employing a position-sensitive detector \([12]\): The scattered atoms eject secondary electrons at the entrance side of the first of two microchannel plates operating in cascade. Depending on the position of the impinging atom the resulting electron cloud will be registered by one of an ensemble of discrete anodes positioned behind the second channel plate. The resulting pulses stop a time-to-amplitude converter started by the photon pulses resulting from the decay of an excited projectile. A multichannel analyser stores the time-of-flight spectra of the coincidence events recorded for each scattering angle. For position decoding different delay times are assigned to pulses from different anodes before feeding them into the time-to-amplitude converter. These delays are chosen in such a way that the coincidence spectra from different angles do not overlap.

An optical lens system of quartz was used since the Mg(3\,\(1P\)--3\,\(1S\)) photons are in the UV region (2,852 Å). A linear polariser (type 105 UVW, 3 M Company) could be inserted into the light path as could a \(\lambda/4\) plate (type S, Dr. Steeg and Reuter Company) for the circular polarisation analysis. The detection efficiency of the optical system is about 2 \(\cdot 10^{-3}\). Since the Mg(3\,\(1P\)--3\,\(1S\)) transition is by far the strongest collision induced line, the UV interference filter having a transmission of only about 14% at 2,852 Å was left out in most of the experiments.

The components of the polarisation vector are

\[
P_1 = \frac{\{I(0) - I(90)\}}{\{I(0) + I(90)\}},
\]

\[
P_2 = \frac{\{I(45) - I(135)\}}{\{I(45) + I(135)\}},
\]

\[
P_3 = \frac{\{I(RHC) - I(LHC)\}}{\{I(RHC) + I(LHC)\}}
\]

where \(I(\alpha)\) is the intensity of the light polarised linearly at the angle \(\alpha\) with respect to the projectile beam axis; RHC and LHC denote right- and left-hand circular polarisation. Representing the excited state Mg(3\,\(1P\)) by

\[
\psi = a_0 |P_0\rangle + a_1 |P_1\rangle + a_{-1} |P_{-1}\rangle
\]

we can parametrise \(\psi\) by means of the two parameters \(\lambda\) and \(\chi\):

\[
\lambda = |a_0|^2/\{|a_0|^2 + 2|a_1|^2\}
\]

and

\[
a_1 = |a_1| \exp(i \chi).
\]

In terms of \(\lambda\) and \(\chi\) the components of the polarisation vector are

\[
P_1 = 2\lambda - 1,
\]

\[
P_2 = -2[\lambda(1 - \lambda)]^{1/2} \cos \chi,
\]

\[
P_3 = 2[\lambda(1 - \lambda)]^{1/2} \sin \chi.
\]

The degree of polarisation

\[
|P| = \left[ P_1^2 + P_2^2 + P_3^2 \right]^{1/2}
\]

is seen to be unity if the ensemble of the excited atoms can be represented by (1). Equation (1) cannot be used, of course, if the Mg(3\,\(1P\)) would be populated by cascades from higher excited states or if several incoherent processes would simultaneously lead to Mg(3\,\(1P\)) excitation without and with inert gas excitation. The degree of polarisation can therefore be used to study the coherence properties of the excitation process.

The primary beam consists of the three Mg-isotopes in their natural abundance. The appropriate isotope correction has been made when calculating the \(\lambda\) and \(\chi\)-parameters. All \(\lambda\) and \(\chi\)-data are corrected for the finite solid angle of the photon detector.

The \(\lambda, \chi\)-parameters are displayed as functions of the impact parameter \(b\). The \(b(\theta)\)-relation was obtained via the classical deflection function using the Mg\(^{0}\)