MASTER

CROSS SECTIONS AND EQUILIBRIUM FRACTIONS
OF DEUTERIUM IONS AND ATOMS IN METAL VAPORS

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MASTER

Submitted by: Thomas J. Morgan, Principal Investigator
Assistant Professor of Physics
Wesleyan University
Middletown, CT 06457

ABSTRACT

The purpose of this program is to measure cross sections and equilibrium fractions of deuterium ions and atoms in metal vapors. In particular, in connection with double charge exchange D^+ ion sources, we are concerned with D^+ formation in alkaline-earth vapor targets. Also, in connection with possible metal vapor contamination in the system, we are concerned with cross sections for high energy D^+ , D^0 and D^- collisions with these metal vapors. Results from this research will fill in a gap in our knowledge of single and double charge transfer and multiple collision processes in alkaline-earth targets and provide a better understanding of D^+ formation mechanisms.

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Discussion of Activity

A. In our last progress report (February 1978, COO-4022-1) we reported that we had just begun to measure equilibrium fractions using alkaline-earth metal vapor targets and preliminary data over a limited energy range was available for $D^+ + Mg, Ba$ collisions. During the period covered by this report we have carried out a comprehensive systematic study of negative ion equilibrium fractions F_{-}^{∞} in Mg, Ca, Sr and Ba using H^+, H^0, D^+ and D^0 projectiles over the broad energy range from 1 to 100 keV. In order to obtain F_{-}^{∞} from our thick target measurements knowledge of both γ^+ and γ^- , the secondary emission coefficient for D^+ and D^- ions, is needed and measurements of γ^+ and γ^- were carried out using D^+ and D^- beams.

B. We have written a computer program to calculate single electron capture cross sections for complex atom targets using the binary encounter approximation, and applied the formalism to Mg and Ba .

C. During the period covered in this progress report three papers on D^+ collisions with alkaline-earth targets have been prepared and submitted to Physical Review A. Also, two contributed and two invited talks have been presented.

D. During the past year our collaboration with Dr. Ron Olson of Stanford Research Institute on D^- formation in alkaline-earth targets has continued, and we have begun a new collaboration with Drs. Carmen Cisneros and Ignacio Alvarez of the University of Mexico. The goal of this new collaboration is to measure the differential scattering cross section for D^- formation in 200 eV to 5000 eV D^+ ion and D^0 atom collisions with alkaline-earth metal vapors. I spent a week at the University of Mexico in December 1978, and we plan to carry out the experiments during the next several months.

Discussion of Results

Cross Sections

We have used the classical binary encounter approximation to calculate the single electron capture cross section σ_{10} for D^+ collisions with Mg and Ba over the energy range from 1 to 100 keV.¹ The calculation agrees with our experimental values to within a factor of 2 over the entire energy range for both Mg and Ba. Based on this agreement we expect the model to predict σ_{10} to within a factor of 2 for other alkaline-earth targets and perhaps for other complex collision systems which have similar internal energy balance.

The high energy structure in our measured single and double electron capture cross sections has been interpreted in terms of target inner shell capture¹, and the experimental results are in accord with Brinkman-Kramers and classical predictions. The structure in our measured D^- formation cross section in Mg at low energies is consistent with a description of double electron capture in terms of transitions via the intermediate $D(1s)$ state, as first proposed by Olson.² Calculations by Olson using a Landau-Zener model agree well with experiment.¹

We have performed an analysis³ based on data available for 16 different collisions between D^+ ions and ns^1 and ns^2 targets (He, H_2 , Li, Na, K, Rb, Cs, Mg, Ba). The analysis demonstrates that the scaling law for the velocity v_m at which the single electron capture cross section is a maximum is not consistent with the Massey adiabatic criterion. Instead, $v_m \propto |\Delta E|^{1/2}$ where ΔE is the energy defect of the collision.

Negative Equilibrium Fractions

Abrupt low energy structure in F_{-}^{∞} is observed using Ca, Sr and Ba (but not Mg) vapors and occurs at approximately the same energy, $E = 5$ keV, in all three targets.⁴ The significant feature of the data is the plateau in the energy range 10 - 5 keV followed by an abrupt rise in F_{-}^{∞} with decreasing energy. This behavior is very different from that in gases or alkali metal vapors. The first measurement of this type of structure was made by Berkner et al.⁵ using Sr vapor. Their data show a rise at low energies with $F_{-}^{\infty} \sim 6\%$ at ~ 3 keV. We have extended their measurements down to 1.8 keV and find F_{-}^{∞} still rising. At 1.8 keV the value of F_{-}^{∞} is $\sim 11\%$. The reason for the abrupt rise in F_{-}^{∞} at low energies is as yet unexplained. At present there appear to be three possible explanations. If we assume the equilibration of D^{-} ions is determined primarily by collisions involving only D^{+} , $D(1s)$ and D^{-} , F_{-}^{∞} can be approximated using a rather simple expression

$$F_{-}^{\infty} = \frac{1}{1 + \sigma_{-10}/\sigma_{0-1}}$$

where σ_{-10} is the electron detachment cross section and σ_{0-1} is the electron attachment cross section.

This equation reveals that, within the framework of a three component model, the large rise in F_{-}^{∞} at low energies is due to an abrupt change in the energy dependence of either σ_{-10} or σ_{0-1} or both. Oscillations in the electron attachment cross section, σ_{0-1} , are predicted by the two-state Struckleburg-Landau-Zener theory of curve crossings and have been suggested by Berkner et al.⁵ as a possible explanation. It is also possible that the electron detachment cross section, σ_{-10} , is a rapidly decreasing function of energy. At low energies the detachment process occurs via electron

association with the target. For alkaline-earth atoms, with an ns^2 configuration and negative electron affinity, low energy detachment is unlikely and σ_{-10} may decrease rather abruptly.²

A third possible explanation involves a four component beam model using D(2s) metastable atoms. Our measurements³ of the D(2s) formation cross section σ_{+m} show that it is large in Ba at low energies. For Mg the D(2s) formation cross section peaks at 14 keV and is small at low energies. The behavior of σ_{+m} suggests that the rise at low energies might be related to D(2s) formation. Inspection of appropriate energy levels for alkaline-earth atoms reveals that several curve crossings exist which could produce D^- ions via D(2s) atoms.

Extrapolation of the present results for Ca and Sr indicate that F_-^∞ may be $\sim 20\%$ at 1 keV. Preliminary calculations by Olson indicate that F_-^∞ is larger in Ca than Cs for $E < 1$ keV - based on estimates of the detachment cross section σ_{-10} and the attachment cross section σ_{0-1} .

It should also be mentioned that for Ca, Sr, and Ba targets, the yield of D^- ions is almost completely independent of the identity of the target over the energy range from 4 to 35 keV.

Secondary Emission Coefficients

We have measured the secondary emission coefficient for H^+ and H^- incident at 90° to a gas-covered stainless steel surface over the energy range from 2.8 keV to 40 keV. Over this entire energy range $\gamma^-/\gamma^+ = 1.5 \pm 0.3$ and extrapolates well to data of J.A. Ray, C.F. Barnett and B. Van Zyl⁶ at 1.6 keV.

References

1. T.J. Morgan and F. Eriksen, Phys. Rev. A, (April 1979).
2. R.E. Olson, private communication.
3. T.J. Morgan and F. Eriksen, accepted by Phys. Rev. A.
4. T.J. Morgan, J. Stone, M. Mayo and J. Kurose, submitted to Phys. Rev. A.
5. K.H. Berkner, D. Leung, R.V. Pyle, A.S. Schlacter and J.W. Stearns, Phys. Lett. 64A, 217 (1977).
6. J.A. Ray, C.F. Barnett and B. Van Zyl, private communication.

Travel During Contract Period

1. Fusion Data Center Meeting, Oak Ridge National Lab., August, 1978.
 2. *American Physical Society Meeting, Madison Wisconsin, December 1978
(D^- Equilibrium Fractions presented).
 3. University of Mexico, Mexico City, December 1978 (Seminar presented on D^+ collisions with alkaline-earth atoms).
 4. American Physical Society Meeting, New York, January, 1979.
- *Travel supported by present contract.

Personnel Involved with Project

1. T.J. Morgan, Principal Investigator.
2. Jack Stone, Postdoctoral assistant supported by present contract.
3. Marguerite Mayo - graduate student.

Papers Prepared During Contract Period *

1. Double Electron Capture in $H^+ + Mg$ Collisions, T.J. Morgan and F. Eriksen, Phys. Lett. 64A, 198 (1978).
2. $H(2s)$ Formation in Proton Alkaline-Earth Collisions, T.J. Morgan and F. Eriksen, Bull. Am. Phys. Soc. 23, 1095 (1978).
3. D^- Production by Multiple Charge-Transfer Collisions in Alkaline-Earth Metal Vapors, T.J. Morgan, J. Stone, M. Mayo and J. Kurose, Bull. Am. Phys. Soc. 23, 1108 (1978).
4. Investigation of Nonadiabatic Effects in Molecular Hydrogen Rydberg States by Electric Field Ionization, T.J. Morgan, C.F. Barnett, J.A. Ray and A. Russek, Phys. Rev. A (September, 1979).

5. Single and Double Electron Capture by 1 - 100 keV Protons in Collisions with Magnesium and Barium, Phys. Rev. A (April, 1979).
6. Formation of Metastable Hydrogen Atoms by Charge Exchange of Fast Protons in Magnesium and Barium Vapors, T.J. Morgan and F. Eriksen, Phys. Rev. A (June, 1979).
7. D^- Production by Multiple Charge-Transfer Collisions in Alkaline-Earth Vapors, T.J. Morgan, J. Stone, M. Mayo and J. Kurose, Phys. Rev. A (July, 1979).

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