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Author
Berkner, Klaus H.

Publication Date
1977-05-01

Submitted to Physics Letters A

LBL-6333 c.)
Preprint
UC-20

Energy and Environment Division

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Klaus H. Berkner, David Leung, Robert V. Pyle, Alfred S. Schlachter and J. Warren Stearns

May 1977

Lawrence Berkeley Laboratory University of California/Berkeley

Prepared for the U.S. Energy Research and Development Administration under Contract No. W-7405-ENG-48

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EQUILIBRIUM CHARGE-STATE FRACTIONS FOR 2.7 - 31 keV DEUTERIUM ATOMS AND IONS IN STRONTIUM VAPOR*

Klaus H. Berkner, David Leung, Robert V. Pyle,
Alfred S. Schlachter, and J. Warren Stearns

Lawrence Berkeley Laboratory
University of California
Berkeley, California 94720

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Abstract

Equilibrium charge-state fractions of 2.7 - 31 keV deuterium in strontium vapor are reported. The energy dependence of the D^- equilibrium yield is discussed. The results are compared with the D^- yield in cesium and magnesium vapors.

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*Work done under the auspices of the U.S. Energy Research and Development Administration.

Negative deuterium-ion formation by charge-transfer collisions of D^+ in gas or vapor targets is of interest both as a basic atomic-collision study and as a promising means to produce intense neutral beams at high energies for plasma heating and fueling.[1] Alkali-metal vapors are often used as charge-exchange media for the formation of D^- beams because of their high conversion efficiencies. The negative-ion conversion efficiency of cesium, for example, reaches 35% at a few hundred eV,[2] but falls to about 3% at 10 keV. At low energies, the intensity and transport of positive-ion beams may be unsatisfactory for some applications; for this reason, it is interesting to search for other charge-exchange media whose maximum negative-ion yields might be greater than in Cs at a higher, more convenient energy. Extrapolation of known cross sections and trends in cross-section data provide some *a priori* expectations that alkaline earths might be such charge-exchange media.[3]

To our knowledge the only alkaline-earth vapor target previously studied as a charge-exchange medium for D^- formation is magnesium,[4,5] for which the yield is about 6% at 3-6 keV. As part of a continuing program to study D^- formation in alkaline-earth targets, we have measured the charge-state fractions in a thick strontium-vapor target for D ions and atoms in the energy range 2.7 - 31 keV.

Our experimental methods and apparatus have been described previously.[4] In brief, D^+ ions were produced in an rf source and were accelerated to the desired energy. The beam thus formed was then modulated, momentum-analyzed and collimated before entering the metal-vapor oven. The oven was heated by electrical-resistance heaters; the temperature was measured by 2 imbedded thermocouples. Target density was inferred from the oven temperature and tabulated vapor-pressure data.[6] The effective beam path length through the oven was about 5.3 cm. The beam leaving the oven was charge-analyzed in a transverse electric field. The D^+ and D^- beams were detected using 2 magnetically-suppressed Faraday cups; the D^o beam was detected using a pyroelectric disk and a lock-in amplifier.[7] All 3 signals were integrated simultaneously. Measurements were made for various target thicknesses up to and beyond charge-state equilibrium. The target thickness required for the D^- fraction to reach 95% of its equilibrium value was approximately 2-3 x 10^{15} cm^{-2} at low energies, dropping to about 1 x 10^{15} cm^{-2} at 10 keV, and rising slightly at higher energies.

The beam leaving the oven can have a broad angular distribution which varies with target thickness. To ensure that the charge-analyzed beams fall within the detectors, we placed a collimator between the oven and the analyzing electric field; the resulting half-angle from the center of the oven to the detectors, through this aperture, was $\pm$ 11.7 mrad. This procedure could cause serious errors in cross-section measurements but should be satisfactory for equilibrium yields. This was demonstrated by careful measurements at target thicknesses up to several times those required for apparent equilibrium. The charge-state fractions did not change, even though the beam transmitted through the target was attenuated by as much as a factor of 10.

Results for the equilibrium charge-state fractions (F_+^∞, F_o^∞, F_-^∞)

for a deuterium beam after passage through a thick Sr-vapor target are shown in Fig. 1. The uncertainty in the results shown for F_+^∞ and F_-^∞ is $\pm$ 7%; the uncertainty in F_o^∞ is less than $\pm$ 5%. Measurements were repeated over the entire energy range over a period of time during which the neutral detector and collimation were changed. We are not aware of any previous measurements with which to compare. A feature to note is the plateau in the F_-^∞ curve between 5 and 10 keV and the rise at lower energies. We speculate that this could result from oscillations in the electron-attachment cross section σ_{0-}. Such oscillations are predicted by the two-state Stueckelberg-Landau-Zener theory of curve crossings[8] and arise when the difference in the potentials between the two-states possesses an extremum. If this model does apply, further structure in F_-^∞ (or σ_{0-}) would be predicted at lower energies, with the extrema having a regular spacing with respect to reciprocal velocity.

Figure 2 shows F_-^∞ curves for a deuterium beam after passage through thick targets of cesium vapor,[2] magnesium vapor,[4] or strontium vapor. Strontium vapor does not appear to offer any advantages over cesium or magnesium vapors for the production of intense D^- beams. However, the rising D^- yield in Sr vapor at low energies does invite further experimental and theoretical investigation of the relevant cross sections. We are planning to extend our thick-target measurements in both Mg and Sr vapors to energies below 1 keV.

We would like to thank Dr. Ron Olson for helpful conversations concerning structure in the equilibrium yield.

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Figure Legends

Figure 1 Equilibrium yields F_{+}^{∞} (■), F_{o}^{∞} (▲) and F_{-}^{∞} (●) for deuterium after passage through a thick strontium-vapor target. The lines are drawn for clarity. Uncertainty in F_{+}^{∞} and F_{-}^{∞} is $\pm$ 7%; uncertainty in F_{o}^{∞} is less than $\pm$ 5%.

Figure 2 Equilibrium yield F_{-}^{∞} for deuterium after passage through thick targets of cesium vapor (dashed line),[2] magnesium vapor (dotted line),[4] or strontium vapor (solid line).

0 0 0 0 4 7 0 0 2 6 3

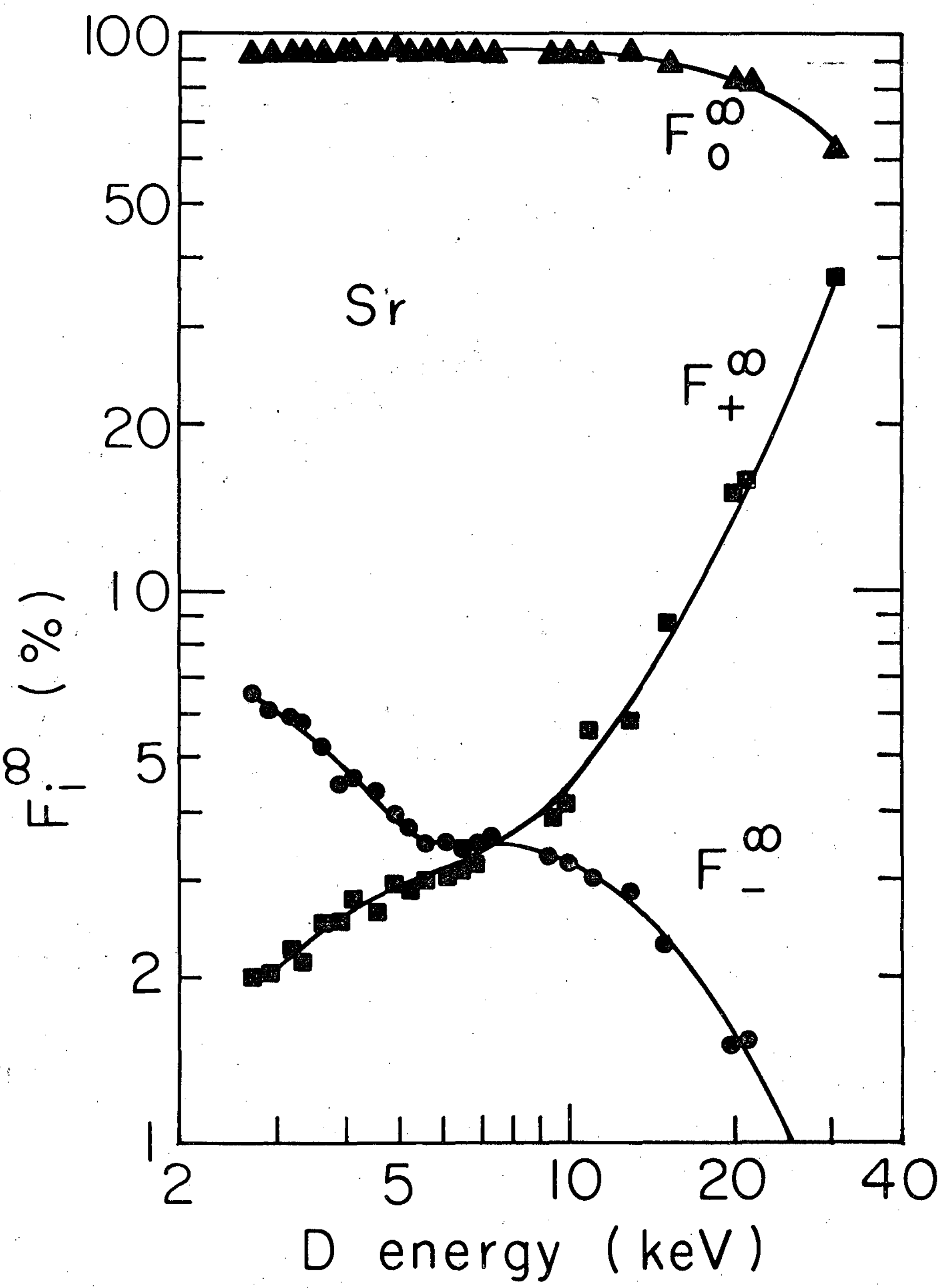

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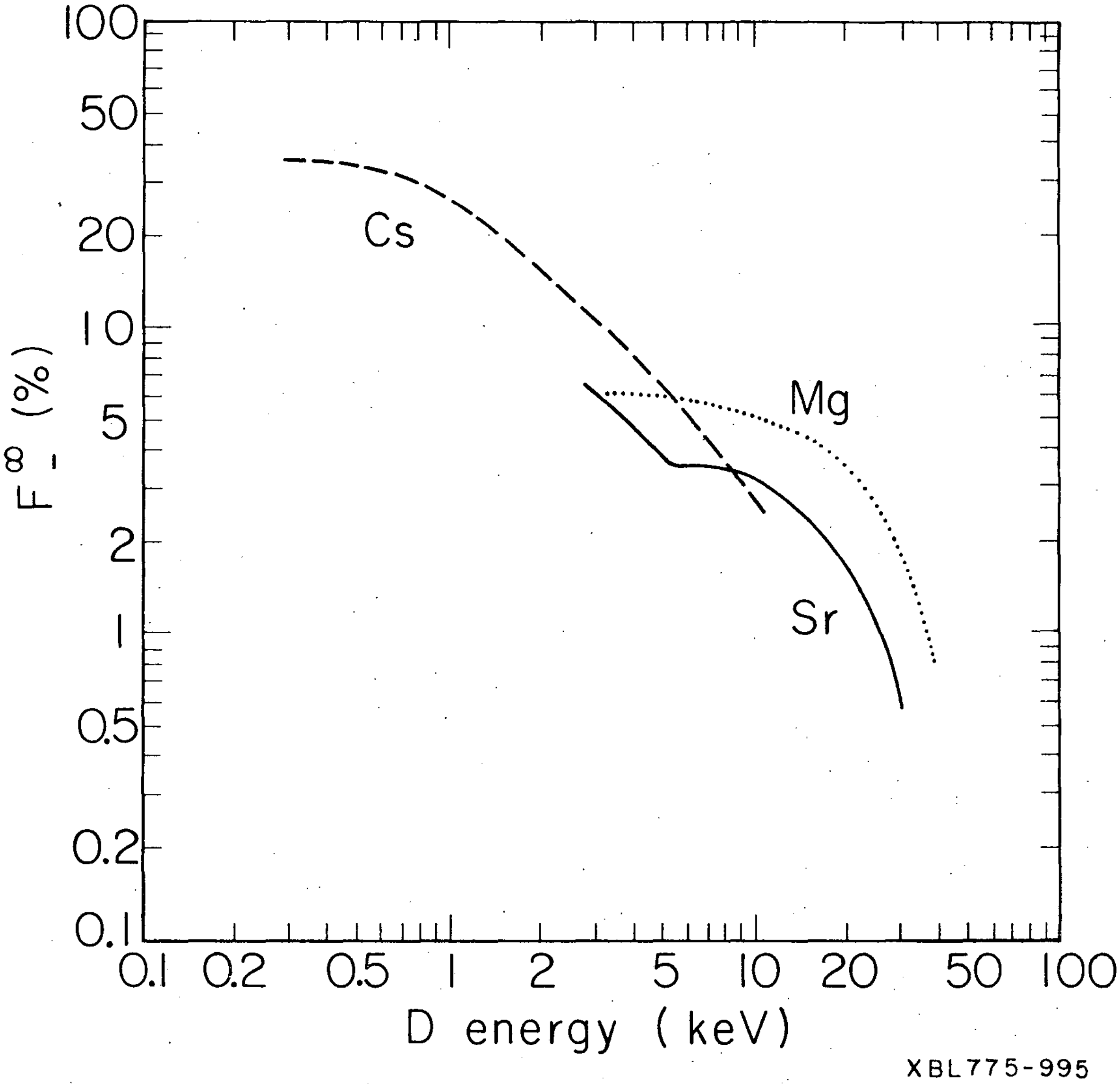
Fig. 1



100
50
20
10
5
2
1
0.5
0.2
0.1
F_-^{∞} (%)
Cs
Mg
Sr
0.1
0.2
0.5
1
2
5
10
20
50
100
D energy (keV)
XBL775-995

Fig. 2

This report was done with support from the United States Energy Research and Development Administration. Any conclusions or opinions expressed in this report represent solely those of the author(s) and not necessarily those of The Regents of the University of California, the Lawrence Berkeley Laboratory or the United States Energy Research and Development Administration.

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