Title

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Publication Date

1975-03-01

Submitted to Physics Letters B

LBL-3694
Preprint c. 1

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March 1975

Prepared for the U. S. Energy Research and
Development Administration under Contract W-7405-ENG-48

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K^- Decay, Hydride Bonds, and Z-dependence in Kaonic Atoms*

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ABSTRACT

The observed low values and striking variations in kaonic x-ray intensities were found to be not due to K^- decay. Measurements on H_2O and CH show greatly reduced x-ray intensities apparently due to the presence of the hydride bonds. A simple cascade calculation with an initial distribution in $n = 30$ that is statistical out to various ℓ_{max} gave agreement with our absolute x-ray intensities. A correlation between ℓ_{max} and atomic spacing is suggested.

We report on a search for orbital K^- decay, notice the effect of hydride bonds, and present a very simple cascade calculation that agrees quite well with the absolute kaonic x-ray intensities.

X-ray intensity-versus-Z measurements are shown in Fig. 1. Open squares are new data; the solid points are from our earlier experiment.(1) Measurements were repeated on several of the targets and we have plotted both the old and the new points except for rare-earth oxides which were replaced by metallic targets. The error bars correspond to statistics only and do not allow for possible error in the absolute calibration which could change the ordinates by an estimated ±15%.

Notice the striking variation of the intensities with Z. This was not expected. Rather, as Z increased, a particular radiative transition was expected to turn on (as E 1 dominated Auger emission), go through a single broad maximum, and then decrease to zero due to nuclear absorption.(2) Instead maxima appear to occur near the Z of completed atomic shells. We have been aware of the resemblance of our intensity curves to a plot of atomic size versus Z (Condo(3) has also recognized this correlation), and, as explained later, we suggest a simple connection between ℓ_{max} of the cascade calculation and the atomic size.

Observe also that the x-ray intensities vary between 0.1 and 0.5 x rays/K_{stop}. Did the remaining 0.9 and 0.5 kaons decay before they could make an observable low n transition? A scintillation counter telescope similar to the one described in Ref. 1 for use in beam calibration was added to the circuitry to look for $K^- \to \mu^- \nu$. We found no evidence for kaon decay in any of the targets. The upper limit for the number of decays amounted to 0.05 K^- decays/K_{stop}. For K^- in liquid He, 0.02 K^- decays/K_{stop} were observed by Fetkovitch et al.(4) Condo(5) and Russell(6) had suggested the possibility of metastable orbits.

In Ref. 1 the x-ray intensities of O from an H_2O target appear to be abnormally low compared to neighboring elements C and Mg. A similar instance of reduced x-ray intensity in a hydride was observed in our most recent experiment. The intensity from a graphite target was 0.5 x ray/K_{stop} whereas a target of scintillator, polyvinyl toluene (CH), yielded 0.1 x ray/K_{stop}.

Only a small fraction of negative kaons are captured by hydrogen in a hydrocarbon. This was demonstrated by Murphy et al.(7) who found that 0.032 of the K^- stopped in a liquid propane (C_3H_8) bubble chamber interacted with free protons. Our observed intensity decrease in CH (and presumably H_2O as well) is probably not due to kaons absorbed by hydrogen. We conclude that the presence of the hydride bonds changed the initial capture distribution of the K^- onto the C and O and/or the cascade process. Furthermore, we suggest that the decreased intensity may be qualitatively understood as due to the shortness of the C-H and H-O-H bonds relative to the C-C and O-O bonds. This could decrease ℓ_{max} of the initial kaon distribution and hence the intensities. In a review article, Ponomarev(8) has discussed the effects of chemical bonding on pions stopped in hydrocarbons.

Our cascade calculation contains electric dipole radiation rates, the free K^- decay rate, and Auger transition rates (using Ferrell's(9) formula with the assumption of immediate refilling of the electron states). The Fried-Martin(10) factor for nuclear motion was included. Nuclear absorption was derived from a simple overlap of the atomic kaon and nuclear Saxon-Woods density distribution. We list the equations used to facilitate comparison with other results.

$\Gamma = W/\hbar \int \rho(r) R^2_{n,\ell} r^2 dr$, sec^{-1}

$W = 4\pi\hbar^2 (1/\mu_K)(1 + m_K/m_N) Im\ a_K$, MeV F^3

$\rho(r) = \rho(0)\{1 + \exp[(r - C)4\ell n3/t]\}^{-1}$, F^{-3}

$A = 4\pi \int \rho(r) r^2 dr$ = mass number

$R_{n,\ell}$ = kaon radial wave function, $F^{-3/2}$

$Im\ a_K = 0.83$ F = effective K^--N scattering length(11)

μ_K = kaon reduced mass; m_K = kaon mass; m_N = nucleon mass

$C = 1.07\ A^{1/3}F$; $t = 2.42$ F.

Initial kaon distributions proportional to $2\ell + 1$ out to ℓ_{max} at $n = 30$ were used to begin the cascade. For each Z the ℓ_{max} that best fit the experimental measurements are shown in Fig. 2. A smooth curve was drawn through these points. For ℓ_{max} values on this smooth curve, the cascade program predicted the curves plotted on Fig. 1.

For such a simple cascade and initial distribution the agreement in absolute intensity is quite good. The tendency of the curves to be high near cut off can be corrected by increasing $Im\ a_K$ or presumably by calculating the nuclear capture rate correctly via the method of Seki.(12) The cascade also predicted <0.002 K decays/K_{stop} for all elements we measured. The cascade predictions for $\Delta n = -2$ transitions uniformly tend to be a factor of 2 higher than our experimental measurements. Of course, other models could be invented to reproduce the observed intensities, but our scheme of truncated statistical distributions is simple and natural. It is worthwhile to show that one such simple scheme can reproduce the observed absolute intensities of the principal lines.

We might expect that the ℓ_{max} of Fig. 2 could be qualitatively obtained from $\ell_{max} = \hbar k_{av} a$ where $\hbar k_{av}$ is the average kaon momentum at capture (the same for all Z) and a is one-half the distance between atoms. The dashed curve is for $\hbar k_{av} = 30$ keV/c. It was chosen to fit ℓ_{max} of the prominent valleys but obviously doesn't fit the rest of the curve.

A ramification of our intensity results was pointed out to us by G. Backenstoss in connection with an experiment on muonic x-ray intensities of elements from S to Mo.(13) Let I_α be the intensity of 2p → 1s transitions and I_β, I_γ, ... intensities of n = 2, 3, ... to n = 1. It was observed that plots of I_β/I_α versus Z showed minima around Z = 19 and rose steeply to a maxima around Z = 25. This behavior would be expected if muons were in angular momentum distributions similar to those we propose for kaons.

Another consequence of the Z-dependence of ℓ distributions involves the polarization of muons in muonic atoms. Retention of the polarization of stopped muons from the instant of atomic capture depends upon the cascade mechanism.(14) It is better preserved if the cascade is through states of maximum ℓ. Arl't *et al.*(15) reported the muon polarization in graphite to be 0.2 but only 0.1 in paraffin (CH). Perhaps a more inward ℓ distribution due to the short hydrogen bond contributed significantly to this result.

A list of all the kaonic x-ray lines measured in our recent experiment is available.(16)

In conclusion we found $<0.05\ K_{decays}/K_{stop}$ in our targets. The short hydride bond seemed to cause a decrease in x-ray intensities. Extensive new data are added to our original absolute intensity measurements. A cascade calculation with the notion of an ℓ_{max} in the initial distribution reproduced our data reasonably well.

It is a pleasure to express our appreciation to Dick Pehl, Fred Goulding, Don Landis, Norman Madden, and William Hansen for furnishing us with the latest models of their superb Ge detector systems; to Billy Abrams for preparing several targets of noxious elements; and to the Bevatron operators.

FOOTNOTE AND REFERENCES

*Work supported by the U.S. Atomic Energy Commission.

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FIGURE CAPTIONS

Fig. 1. Intensity versus Z of observed principal ($\Delta n = -1$) kaonic x-ray lines. Error bars include statistical uncertainties in the numbers of recorded x rays, but do not include errors in the absolute numbers of stopped kaons which we estimate to be ±15%. Filled-in circles apply to data of Ref. 1, open squares to our recent experiment. The smooth curve shows the intensities calculated by a cascade program that used the ℓ_{max} of Fig. 2.

Fig. 2. Plot of ℓ_{max} versus Z that best fit the experimental data. The solid curve was drawn by eye. An attempt was made to qualitatively fit the data with an arbitrary constant kaon momentum of 30 keV/c at capture. The dashed curve shows that the resulting ℓ_{max} for lever arms of one half the distance between atoms did not fit.

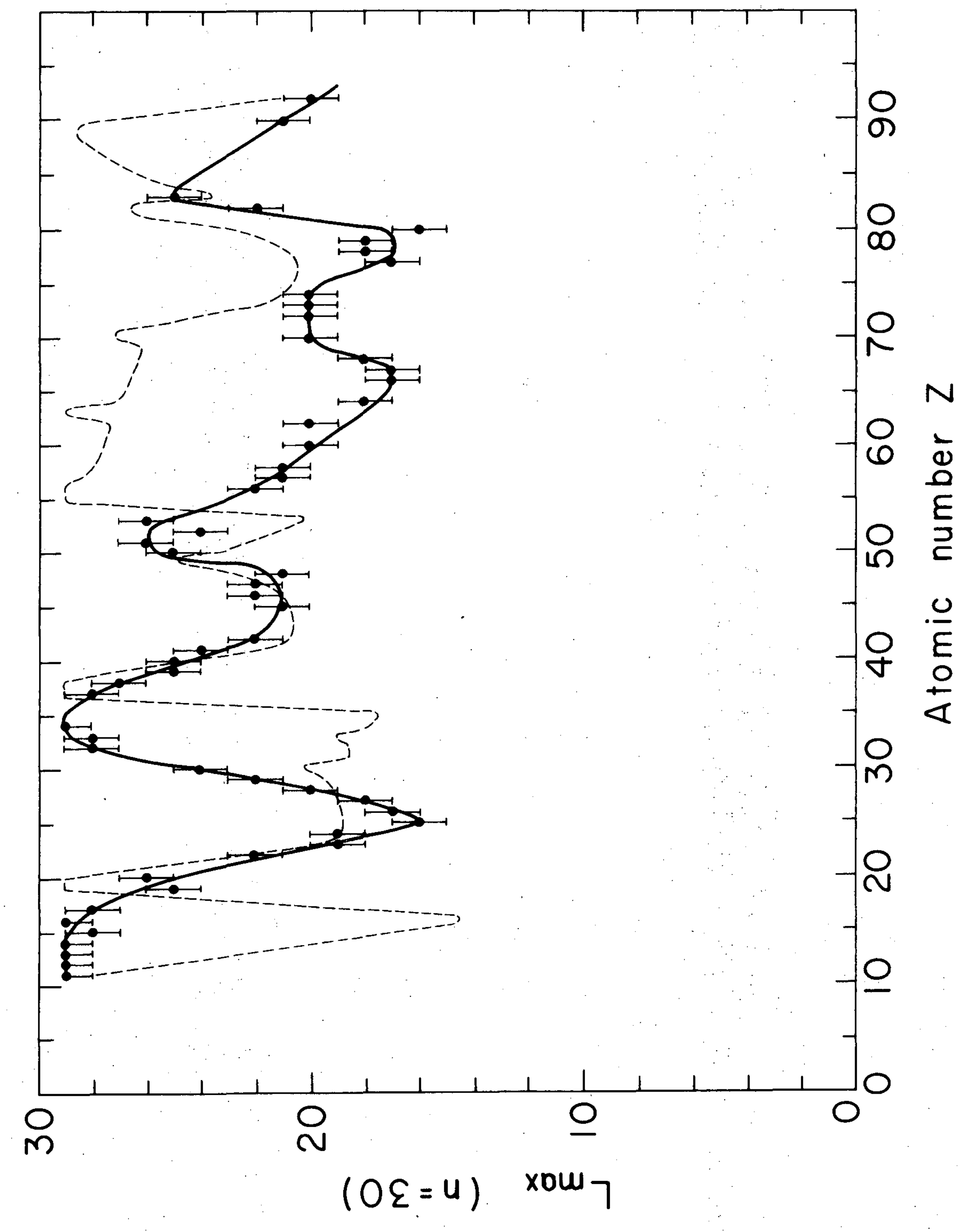

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Fig. 1

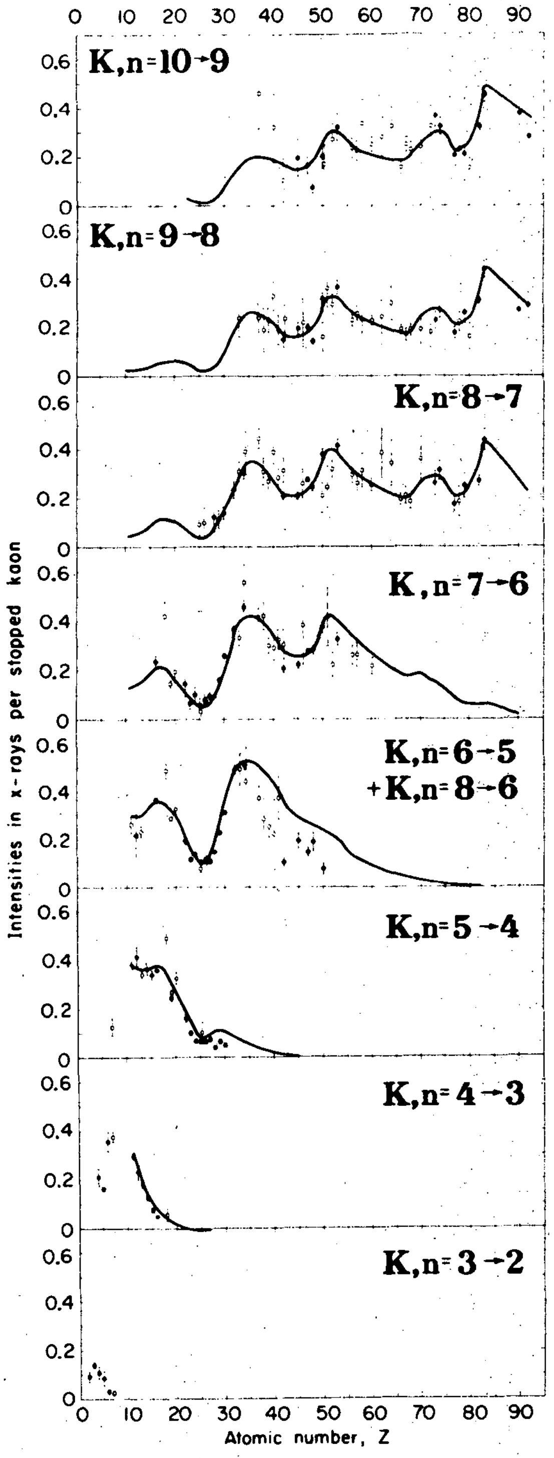

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Fig. 2

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