

Lawrence Berkeley National Laboratory

Recent Work

Title

CHEMICAL EFFECTS IN THE CAPTURE OF NEGATIVE MUONS

Permalink

<https://escholarship.org/uc/item/7x19r20k>

Authors

Mausner, L.F.
Naumann, R.A.
Monard, J.A.
[et al.](#)

Publication Date

1975

Submitted to Physics Letters B

RECEIVED
LAWRENCE
RADIATION LABORATORY

LBL-3692
Preprint c.1

MAR 24 1975

LIBRARY AND
DOCUMENTS SECTION

CHEMICAL EFFECTS IN THE CAPTURE OF NEGATIVE MUONS

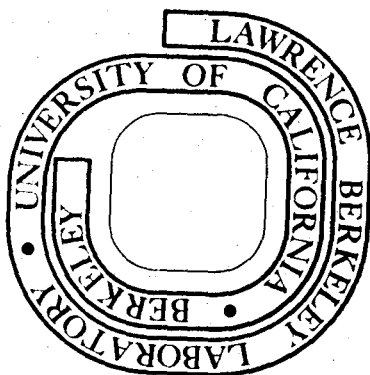
L. F. Mausner, R. A. Naumann, J. A. Monard,
and S. N. Kaplan

January 1975

Prepared for the U. S. Atomic Energy Commission
under Contract W-7405-ENG-48

For Reference

Not to be taken from this room



LBL-3692

c.1

DISCLAIMER

This document was prepared as an account of work sponsored by the United States Government. While this document is believed to contain correct information, neither the United States Government nor any agency thereof, nor the Regents of the University of California, nor any of their employees, makes any warranty, express or implied, or assumes any legal responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by its trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof, or the Regents of the University of California. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof or the Regents of the University of California.

CHEMICAL EFFECTS IN THE CAPTURE OF NEGATIVE MUONS*

L. F. Mausner, R. A. Naumann, Joseph Henry Laboratories of Physics and

Frick Chemistry Laboratory, Princeton University

J. A. Monard, S. N. Kaplan, University of California, Lawrence Berkeley Laboratory

Muonic Lyman-series X-ray spectra have been measured for several isoelectronic and isostructural molecular series and related pure elements. Seven muonic Lyman series lines were observed from liquid argon with relative intensities consistent with neighboring isoelectronic ions, but in stark contrast to the single line previously reported for a gaseous argon target. The measured relative capture rates and Lyman intensity correlations provide new evidence for chemical structure influences on the capture of negative muons.

Experiments in the last decade indicate that molecular or atomic structure of matter influence the capture of negative muons. A current model [1] interprets these chemical effects by predicting a considerable fraction of muons slowed in covalent compounds are initially captured in multicenter molecular orbitals rather than individual atomic orbitals. Atomic capture probabilities can be experimentally deduced from measurements of the integrated intensity of muonic X-rays from individual elements. Also, the initial muon angular momentum distribution is reflected in the relative intensities of the Lyman series.

We have exposed several isoelectronic sequences of compounds to muons at the 184" Cyclotron. The muonic X-ray spectra were recorded with a Ge(Li) detector system. Relative intensities were determined using an efficiency calibrated detector and correcting for target attenuation.

Special interest attaches to the liquid Ar target besides its position in the isoelectronic series Ar, KCl, CaS. Backenstoss et al. [2] at CERN using a high pressure Ar target, observed only the single K_{α} line ($2p \rightarrow 1s$). The reported intensity limit, $K_{\beta}/K_{\alpha} < 0.02$, implies that in this cascade nearly all the muons occupied circular orbits ($l_{\mu} = n-1$). This unexpected result disagrees with earlier low resolution NaI work of Budyashov et al. [3]. The spectrum we observe for liquid Ar, clearly showing (fig. 1) seven Lyman series members, is similar to that of neighboring isoelectronic ions (table 1); the intensity ratio K_{β}/K_{α} is 0.072 ± 0.004 . Assuming the validity of the CERN observation, these results imply a large physical state effect for muon capture in liquid or gaseous argon.

An Auger [4,5] mechanism is usually invoked for initial muon capture from the continuum. The physical state of a large assembly of molecules could influence this process if the Auger rate were sensitive to the angular momentum of this continuum muon. An apparent modulation of the K_{β}/K_{α} ratio in muonic atoms correlating with atomic size has been pointed out by Condo [6]. He proposes that the angular momentum distribution of the initially captured muons is sensitive to varying internuclear separation of the absorbing material. Classically, larger atomic size allows higher

initial angular momentum for the captured muon, thus tending to lower the K_{β}/K_{α} ratio.

The measured Lyman intensities (table 1) for the isoelectronic series S^{-2} , Cl^{-1} , Ar , K^{+} , Ca^{++} shows that the K_{β}/K_{α} ratio decreases with decreasing ionic radius [7] (r), a trend apparently opposite that expected from Condo's arguments. However, the ionization potential (E) taken with the virial theorem provides an estimate for the upper limit of the angular momentum of a bound muon at the valence radius of an atom (or ion), $L_{\max} = r(2M_{\mu} E)^{\frac{1}{2}}$. Comparing the trend in L_{\max} ($\propto rE^{\frac{1}{2}}$) with the measured K_{β}/K_{α} ratio, we obtain (except in the case of Ca^{++}) qualitative correlation between model and experiment. If one alternatively assumes the K_{β}/K_{α} ratio relates to the function rE^x , where $1/2 < x \leq 1$, the correlation is complete. Uncertainties in our measured intensities for the higher Lyman series lines do not permit similar conclusions for higher levels. For the data of Quitmann et al. [8] employed by Condo, the ionization potentials are roughly constant so the atomic size effect would then predominate as he proposes.

Table 2 shows that the Lyman mesic intensity ratios also correlate with the chemical structure of the targets. The intensity patterns for the chlorine ion (Cl^{-}) in $NaCl$, KCl , and $CaCl_2$, for the calcium ion in CaS and $CaCl_2$, for the sodium ion in $NaCl$ and $NaClO_4$, and for S in $CaSO_4$ and $MgSO_4$ are all similar. Conversely, differences are observed for S between CaS and $CaSO_4$ and for Cl in $NaCl$ and $NaClO_4$.

By summing Lyman series intensities relative capture probabilities per atom in the compounds were obtained. The capture ratios measured for the solids containing ions isoelectronic with argon (KCl and CaS) are: $K^{+}/Cl^{-} = 1.16 \pm 0.03$ and $Ca^{+2}/S^{-2} = 1.57 \pm 0.04$, compared to Z Law [9] predictions of 1.12 and 1.25 respectively. This trend, suggesting capture rate enhancement with increasing ionic charge is consistent with recent Monte Carlo trajectory calculations for these ionic salts by Haff et al. [10].

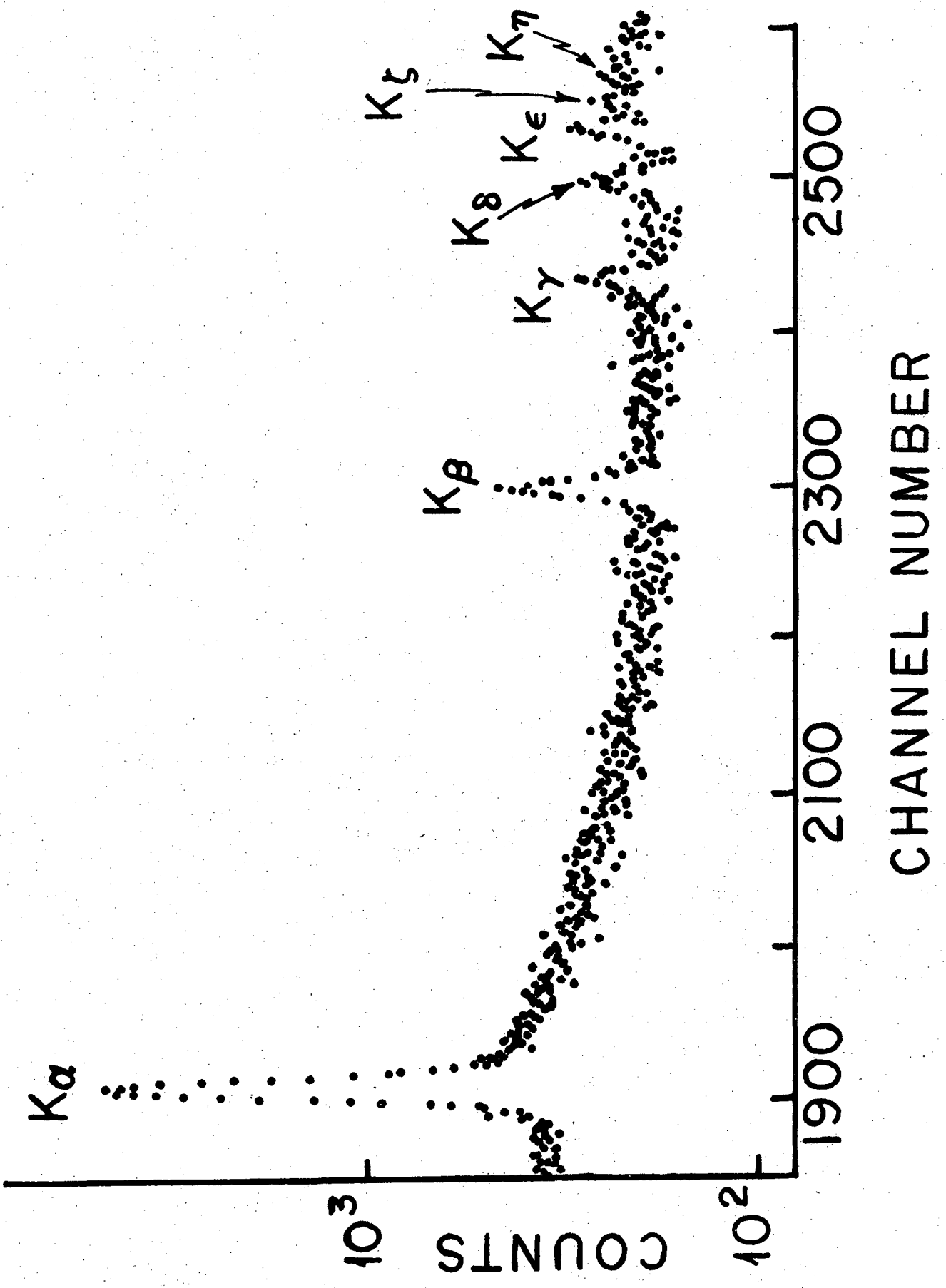
We have compared atomic capture probabilities for the salts NaCl, NaClO₄ and CaS, CaSO₄ with the results Na/Cl = 0.68 ± 0.04, 0.73 ± 0.04 and Ca/S = 1.57 ± 0.04, 1.83 ± 0.06 respectively. (For NaCl Zinov et al. [11] has reported Na/Cl = 1.05 ± 0.07 from lower resolution data using NaI detectors). These observed decreases in relative capture probability for an atom when tetrahedrally coordinated by four oxygen atoms suggests preferential transfer of muons, initially captured on the central sulfur or chlorine atom, to the coordinated electronegative oxygen atoms.

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

- [1] L. I. Ponomarev, Ann. Rev. Nucl. Sci. 23 (1973) 395.
- [2] G. Backenstoss et al., Phys. Lett. 36B (1971) 422.
- [3] Yu G. Budyashov et al., Sov. J. Nucl. Phys. 5 (1967) 426.
- [4] M. Au-Yang and M. L. Cohen, Phys. Rev. 174 (1968) 468.
- [5] P. K. Haff and T. A. Tombrello, Ann. of Phys. 86 (1974) 178.
- [6] G. T. Condo, Phys. Rev. Lett. 33 (1974) 126.
- [7] Handbook of Chem. & Phys., Chemical Rubber Co., 51st ed. (1971)
- [8] D. Quitmann et al., Nucl. Phys. 51 (1964) 609.
- [9] E. Fermi and E. Teller, Phys. Rev. 72 (1947) 399.
- [10] P. K. Haff, P. Vogel, V. Akylas and A. Winther, Bull. Am. Phys. Soc.
20 (1975) 91.
- [11] V. G. Zinov, A. D. Konin and A. I. Mukhin, Sov. J. Nucl. Phys. 2 (1966) 613

Figure Caption:

Fig. 1 Lyman series muonic X-rays from liquid argon.



CHANNEL NUMBER

Table 1. Intensity Ratios in an Isoelectronic Series

	S ²⁻	Cl ⁻	Ar	K ⁺	Ca ⁺⁺	Ca	S
Radius (r)	1.90	1.81	1.88	1.33	0.94	1.97	1.04 Å
Ionization Potential(E)	-11.75	3.61	15.76	31.81	51.21	6.11	10.36 eV
$rE^{\frac{1}{2}}$	—	3.44	7.46	7.50	6.73	4.87	3.35 Å (eV) ^{1/2}
rE	—	6.53	29.63	42.31	48.14	12.04	10.77 Å eV
$K_{\beta}/K_{\alpha} \times 10^3$	89±7	81±5	73±4	73±4	64±4	79±3	79±3
$K_{\gamma}/K_{\alpha} \times 10^3$	25±5	23±4	20±3	29±3	22±4	25±2	39±3
$K_{\delta}/K_{\alpha} \times 10^3$	23±5	24±4	23±4	29±4	23±4	25±2	45±2
$K_{\epsilon}/K_{\alpha} \times 10^3$	16±5	15±4	21±3	26±3	19±4	23±2	30±2
$K_{\zeta}/K_{\alpha} \times 10^3$	7±4	4±3	12±3	13±3	8±4	15±2	20±2
$K_{\eta}/K_{\alpha} \times 10^3$			12±3	10±4	8±5	12±2	7±2
$K_{\theta}/K_{\alpha} \times 10^3$				7±4		2±1	5±2

00004301985

Table 2. Lyman Series Intensity Ratios ($\times 10^3$)

Ion	K_{β}/K_{α}	K_{γ}/K_{α}	K_{δ}/K_{α}	K_{ϵ}/K_{α}	K_{ζ}/K_{α}
$\text{Cl}^{-}(\text{KCl})$	81±5	23±4	24±4	15±4	4±3
$\text{Cl}^{-}(\text{NaCl})$	73±4	21±3	31±3	20±3	9±3
$\text{Cl}^{-}(\text{CaCl}_2)$	73±3	31±2	28±2	23±2	10±2
$\text{Cl}(\text{NaClO}_4)$	77±6	48±5	46±5	31±5	19±5
$\text{S}^{-2}(\text{CaS})$	89±7	25±5	23±5	16±5	7±4
$\text{S}(\text{CaSO}_4)$	89±9	37±7	52±8	38±8	16±7
$\text{S}(\text{MgSO}_4)$	79±6	33±5	33±5	33±5	
$\text{Ca}^{++}(\text{CaS})$	64±4	22±4	23±4	19±4	8±4
$\text{Ca}^{++}(\text{CaCl}_2)$	64±4	22±3	26±3	18±3	12±3
$\text{Na}^{+}(\text{NaCl})$	100±11	71±9	42±6	18±5	
$\text{Na}^{+}(\text{NaClO}_4)$	112±13	79±10	47±8	19±6	

LEGAL NOTICE

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Atomic Energy Commission, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

TECHNICAL INFORMATION DIVISION
LAWRENCE BERKELEY LABORATORY
UNIVERSITY OF CALIFORNIA
BERKELEY, CALIFORNIA 94720