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Nuclear Chemistry Progress Report

During the past year our experimental and theoretical investigations of chemical bonding influences on the moderation and capture of negative mu mesons when stopped in matter has developed well. Two separate experiments with collaboration at the 184 inch cyclotron of the Lawrence Berkeley Laboratory and at the Los Alamos Meson Facility have been completed and clearly demonstrate the chemical effects of interest to us. Dr. Leonard F. Mausner has completed his thesis research program and is now continuing postdoctoral research in this area at Los Alamos. These initial experiments have provided us with a valuable experimental background needed to develop our continuing program.

Our spectroscopy program using the Q3D magnetic spectrograph at the Princeton cyclotron has also progressed most satisfactorily. We have completed our studies of the three odd nuclei ^{101}Rh , ^{105}Ag and ^{107}Ag using the (p,t) reaction. The high resolution of this apparatus has enabled us to discover numerous negative parity doublets in the level schemes of these three nuclei. The generally occurring doublet structure is not accounted for by the usual theoretical treatment of quadrupole or octupole phonon-particle coupling since the ground state particle angular momentum for these nuclei is $\frac{1}{2}$. We are extending our (p,t) studies to other even nuclei and odd nuclei with spin $\frac{1}{2}$ in this region. Our objective is to recognize those features of the collective modes which are evidenced by the p,t reaction and to study further examples of particle spin $\frac{1}{2}$ coupling in this region.

Our studies of internal fields in solids using time dependent perturbed gamma ray angular correlation is continuing. Our experiments depend upon an electric field gradient of a solid acting on a nuclear quadrupole moment. The temperature dependence of the electric field has been of particular interest to us. In studies of radioactive indium 111 implanted in vanadium trioxide we observe a total attenuation of the angular correlation at liquid nitrogen temperature and associate this with the conducting - non conducting transition of vanadium trioxide

at 153°C. We continue our collaboration with staff members at the Bell Telephone Laboratories.

Finally we have been comparing the exact quantum mechanical and semiclassical treatments of a particle moving in various central force potentials. These studies are intended to examine the validity of certain semiclassical approximations which have been made in the treatment of nuclear rotational motion.

Chemical Structure Effects in the Capture of Negative Muons in Matter (L. F. Mausner and R. A. Naumann with Selig Kaplan and Joyce Monard, Lawrence Berkeley Laboratory and Jere Knight and Carl Orth, Los Alamos Scientific Laboratory)

We have completed a 200 hour experiment at the stopping muon channel of the 184 inch cyclotron of the Lawrence Berkeley Laboratory. The objective of this experiment was to compare characteristics of the muon capture process in a material containing single atoms with ionic salts containing ions of related electronic structure. The single atom system chosen was argon in the liquid phase and the ionic salts of particular interest were potassium chloride and calcium sulfide which are composed of ions isoelectronic with argon. Our experiment was motivated by an apparently anomalous mu mesic K X-ray spectrum reported by the CERN group for capture of mu mesons in high pressure gas. These results indicated an almost complete absence of higher p states populated in the muon cascade of argon. The data shown in Table I indicate that for liquid argon and the isoelectronic ions, the mesic K X-rays intensities are closely similar with a regular trend toward decreasing K_{β}/K_{α} intensity as one proceeds from the sulfide ion through the argon atom to the calcium ion. The marked difference between the K mesic X-ray intensity pattern for ionic salts containing sulfur and chlorine in the simple chloride and sulfide ions and the oxyanions perchlorate and sulfate are shown in figures 1 and 2 which display data from tables I and II. The similarity of the K X-ray pattern from the ionic chlorides is striking; this suggests that for ionic crystals a given ion yields a characteristic mesic X-ray pattern irrespective of the counter ion. The data for the sodium K X-rays from solid sodium chloride and sodium perchlorate and for the calcium K X-rays from calcium sulfide and calcium chloride support this suggestion. For the tetrahedral oxy-anions sulfate and perchlorate involving tetrahedral covalent bonding of the central atom to oxygen atom figures 1 and 2 show there is a marked increase in the intensities of the higher members of the K X-ray transitions

from the sulfur and chlorine. Some results of our experiments at Berkeley have been summarized in a paper recently published in Physics Letters B; a copy is attached to this report.

The experiments at the Los Alamos meson facility have studied the capture of negative mu mesons in covalently bonded elements and compounds, metallic oxides of transition elements and aqueous solutions of ionic alkali halides. Some principal results of the Los Alamos experiments include: (1) observation that the muonic K X-ray intensity pattern from carbon in the diamond and graphite forms are the same within experimental accuracy in spite of the large differences in the chemical bonding and electrical conductivity of these two allotropic modifications (2) observation of an unexpectedly large difference in the muon capture probabilities for boron and nitrogen when combined in either of the two allotropic forms of the compound boron nitride, BN. The nitrogen capture probability exceeds four times that of boron. (3) observation of a markedly different intensity pattern for the mesic K X-rays from carbon and nitrogen when bound in inorganic or organic compounds. For the organic compounds the higher members of the K series are markedly enhanced. (4) the verification of the constant muon capture probability for aqueous ions. This is in accord with the expectation that in dilute solution the energy spectrum of the muons when captured is constant and determined by the major component - water. Our results are being summarized in a paper being prepared for publication.

In the following experimental period at Los Alamos, experiments will be undertaken to determine if diffusion and Coulomb stripping of the neutral system proton-negative muon ("pseudoneutron") can account for the different K X-ray intensity patterns we observe in organic compounds where hydrogen is present. A comparison of the meson K intensity pattern from nitrogen and oxygen for pairs of compounds such as pentachloronitrobenzene and nitrobenzene ($C_6Cl_5NO_2$ and

$C_6H_5NO_2$) and comparisons of the carbon capture spectrum from benzene, hexachlorobenzene and trichlorobenzene (C_6H_6 , C_6Cl_6 , and $C_6Cl_3H_3$) as well the deuterated analogs (C_6D_6 , $C_6Cl_3D_3$) should verify the extent to which diffusion of "pseudoneutrons" are involved when negative muons are captured in hydrogen containing compounds.

μ^- K X-RAY INTENSITY PATTERN

Fig 1

μ^- K X-RAY INTENSITY PATTERN

Fig 2

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

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	

Study of the (p,t) Reaction at Nuclei Around A = 100 (R. Del Vecchio, K. Krien I. Oelrich and R. A. Naumann)

In order to compare with the predictions of the weak coupling model for odd A nuclei with ground state spin $\frac{1}{2}$ we have studied the $^{107,109}\text{Ag}(p,t)$ $^{105,107}\text{Ag}$ as well as the $^{103}\text{Rh}(p,t)^{101}\text{Rh}$ reactions using the Princeton University sector-focus cyclotron and Q3D spectrometer. Ground state spin $\frac{1}{2}$ target nuclei are of particular interest for such investigations since the coupling of the $I=\frac{1}{2}$ particle ground state to phonon excited states of an even core results in a coupling forming level doublets. This restriction in the number of states aids considerably in identifying the core coupling pattern.

Our experiments are being carried out using a 30 MeV proton beam from the Princeton cyclotron, the QDDD spectrograph, and targets of about $100\mu\text{g}/\text{cm}^2$ evaporated onto $20\mu\text{g}/\text{cm}^2$ carbon backings. The energy resolution obtained is typically 10 keV. The results of these experiments are summarized in Figs. 3 and 4. The doublet level structure is striking. The first $3/2^-$, $5/2^-$ doublets correspond to the coupling of the odd particle to the first phonon ($I=2$) state occurring at about 500 keV in the even core nuclei. The doublets with spins $3/2^-$, $5/2^-$ and $7/2^-$, $9/2^-$ around 1 MeV corresponding to coupling involving the 2^+ , and 4^+ members of the 2 phonon excitations. The $\frac{1}{2}^-$ excited state corresponding to the coupling to the 0^+ 2 phonon state is either only weakly excited or greatly displaced in energy. The doublet corresponding to the octupole excitation is also seen. Preprints of articles accepted for publication in the Physical Review C are attached to this report.

In the continuation of our research of the (p,t) reactions on even nuclei around A = 100, we are investigating the even even nuclei $^{106,104}\text{Pd}$. These represent the core nuclei for the $^{105,107}\text{Ag}$ isotopes mentioned above. The main object of these experiments was to locate the one, two and possibly

the three phonon multiplets in the core nuclei and compare the reaction strengths of these states with the corresponding strength in the odd isotopes. We also wanted to investigate the 3^- octupole state for further comparison with the odd nuclei. For these experiments we used targets of enriched ^{106}Pd and ^{108}Pd evaporated onto $20\ \mu\text{g}/\text{cm}^2$ carbon backings. The target thicknesses employed were approximately $100\ \mu\text{g}/\text{cm}^2$. In order to derive absolute cross sections, a preliminary study of these targets in the large scattering chamber of the Princeton cyclotron using (p,p') and (p,t) reactions to excite nuclear ground states was conducted for angles from 10° to 50° in 5° steps. The main experiment was then made in the QDDD spectrograph with 30 MeV protons. Spectra were taken at angles from 10° to 50° in 5° steps. Examples of these spectra at 20° are shown in Fig. 5. The overall energy resolution obtained was 12 keV, which is insufficient to completely resolve the two phonon multiplets at 1330 keV in ^{104}Pd and 1130 keV for ^{106}Pd . The angular distributions observed for these multiplets indicate dominant $L=0$ transfer strength. In view of this strong population of this $0^+ 2$ phonon state, it is surprising that the $\frac{1}{2}^-$ members of the 2 phonon quintet in the odd $^{105}, ^{107}\text{Ag}$ isotopes are either greatly shifted from the $3/2, 5/2, 7/2, 9/2$ members of the quintet or are negligibly excited. Candidates for the 3^- octupole state may be found above 2 MeV excitation but definite conclusions await completion of the analysis of these data.

Experiments on $^{89}\text{Y}(p,t)^{87}\text{Y}$ and $^{88}\text{Sr}(p,t)^{86}\text{Sr}$ are an extension of the program to examine the applicability of the weak coupling model to odd nuclei with ground state spin $\frac{1}{2}$. ^{86}Sr represents the core for ^{87}Y . The experimental procedures are similar to those we have employed previously. Thicker targets of about $250\ \mu\text{g}/\text{cm}^2$ and higher beam energy of 42 MeV protons yield an overall resolution of 15 keV in these experiments. The patterns of the strongly excited states appear similar in the even and odd isotopes. In particular, we note the similarity in energy and in strength of the (p,t) peak at 1077 keV and 990 keV in the ^{86}Sr and ^{87}Y respectively. The detailed analysis of these data is presently underway. See Figs. 6, 7.

NEGATIVE PARITY DOUBLETS $^{105,7,9}_{47}\text{Ag}$

OCTUPOLE DOUBLET

ONE, TWO PHONON DOUBLETS

Fig 6

-7e-

Study of Nuclear Quadrupole Interactions in Solids using Perturbed Gamma-Ray Angular Correlations (S. Lis, E. Ansaldi, K. Krien, and R. A. Naumann)(with R. Raghavan, P. Raghavan and E. Kaufman, Bell Telephone Laboratories)

The nuclear hyperfine interaction studies by Time Dependent Perturbed Angular Correlation (TDPAC) has continued during the last year. Our gamma-gamma angular correlation equipment has been modified to permit automatic sequential angle changes between the 90° and 180° positions. A thin NaI(Tl) crystal has been acquired which permits detection of low energy gamma rays, an oven, for controlling the temperature of samples, has been built; this holds the temperature of a sample constant (to within 2° C for 24 hours) and enables us to study hyperfine interactions as a function of sample temperature. The present heating range of this oven is from room temperature to 270° C, and can be easily extended. By using Dewar flasks, the temperature of a sample can also be lowered down to 77° K. This range now permits us to carry out, at Princeton, accurate temperature dependent studies of the electric field gradients in materials using the TDPAC method.

We are now determining the dependence of the quadrupole interaction upon conductivity. It is well known that nuclei which undergo electron capture do not provide good probes when studying insulators; transient atomic charge states are created in the electron capture process which do not allow unique configurations to be established near the probe atom. In contrast, conductors do not pose this problem for radioactive probes that undergo electron capture since the transient charge states relax quickly. Vanadium trioxide (V_2O_3) is a material which undergoes a phase transition at 153° K from a phase exhibiting metallic conduction to an insulating phase. This material has been well studied using the Mossbauer effect, and hyperfine fields have been observed in both phases using ^{57}Fe . When this material is doped using the electron capture probe ^{111}In ,

a clear hyperfine interaction rotational pattern was observed using the TDPAC technique, but no unique hyperfine interaction frequency could be seen in the insulator phase, where Mossbauer work revealed a strong interaction. Figures 8a) and 8b) show the time dependent correlation patterns for the two temperatures, above and below the transition temperature. In an attempt to pursue this study, vanadium dioxide (VO_2) has also been used as a host. However, for this compound doped with the ^{111}In again no unique hyperfine interaction frequency was observed in the gamma-ray angular correlation work.

The non-cubic semiconductors, tellurium and selenium, have been chosen as promising hosts for our future experiments which will also include a study of Ag - Cd alloys for which the electron concentration is known to vary with the ratio of the two components.

A study of the temperature dependence of the quadrupole interaction of ^{111}In in antimony is in progress. In the preparation of the antimony samples with carrier free ^{111}In , a low amplitude pattern was observed, but those samples that contain a small additional amount of inert indium carrier (<.1%) produce an easily recognizable interaction. Figure 9 shows the correlation pattern of antimony with carrier amounts of indium added. This seems to agree with the results of E. Bodenshtedt et al. (Phys. Rev. B6, pp 2909-22). Their study of ^{111}In in cadmium yielded a similar result. These authors explained their observation by hypothesizing that carrier free indium collects along the crystalline grain boundaries in non-unique sites, however, when sufficient indium is present to fill the boundary sites, dissolution of indium into the bulk host occurs.

Future research using ^{204}Pb as a probe to investigate non-cubic metals is planned, as well as the use of the 1426 keV, 6^+ state in ^{210}Po as a probe.

*A preprint of a paper for publication in Physical Review Letters follows.

-9a-

Quadrupole rotation spectra for the 247 keV,
5/2 state of ^{111}Cd in V_2O_3

Quadrupole rotation spectrum for the 247 keV,
5/2 + level of ^{111}Cd in Antimony at 297 °K

Isotope Separator Program (F. Loeser, E. Ansaldi, and R. A. Naumann)

In connection with the nuclear spectroscopy research and our perturbed gamma ray angular correlation investigation it has been of interest to have radioactive sources of 55 minute cadmium 105 and 8.3 hour astatine 210. The first isotope populates levels in silver 105, one of the nuclei under investigation in our (p,t) research program. The astatine 210 populates the 39 nanosecond 1472 keV 6^+ level in polonium 210 which will be used to probe internal fields in solids by implanting the radioactive astatine 210 with the isotope separator.

In both cases the high temperature on-line ion source previously used for the preparation of radioactive zinc isotopes by alpha particle bombardment of nickel has proved suitable for on-line production of the cadmium and astatine radioisotopes. The cadmium 105 has been prepared by 22 MeV proton bombardment of a target consisting of natural palladium powder mixed with graphite contained in a resistance heated tungsten tube. 30 MeV alpha particle bombardment of a bismuth powder-graphite mixture yielded the astatine isotope. 45-1

The original isotope separator beam scanning equipment has been replaced after ten years of hard use. The new beam scanning equipment is of Danish manufacture and distributed by High Voltage Engineering Corporation. The new equipment is functioning very well with far better ion current sensitivity and lower noise. The availability of this new equipment has inspired a detailed study of the beam focussing in the isotope separator which is underway.

Quantum Mechanical Calculations For The Nonrelativistic Particle In A Central Force Potential (D. Allred and R. A. Naumann)

The nonrelativistic problem of a point particle moving under the influence of the central force potential $V = ar^s$ (1) is of great general interest. When treated exactly by classical mechanics, the case of $s = -1$ results in the Keplerian problem of planetary motion under a gravitational potential. Similarly, the semiclassical and exact quantum mechanical solutions for the same problem obtained by Bohr and Schrödinger respectively, yielded the quantum states of the hydrogen atom. These in turn provided the framework for discussing the structure of many electron atoms and molecules. The case of $s = +2$ treated quantum mechanically provides eigenfunctions and eigenvalues for the isotropic harmonic oscillator in 3 dimensions, results of fundamental importance to understanding nuclear shell structure. The quantum mechanical treatments for potential with other values of s do not yield eigenfunctions or eigenvalues in closed form, instead these must be found using computers, approximation techniques or semiclassical approaches. These other potentials are of interest also because zeropoint energies and rotation-vibration coupling enters, features which are necessarily involved in recent treatments of the rotation of moderately deformed nuclei. To examine these problems, we are comparing the exact eigenvalues of the potentials where $-1 < s < +\infty$ calculated with a computer with the eigenvalues obtained using semiclassical phase integral techniques.

We are interested in "simple" formulae which yield the energy eigenvalues for a given potential in terms of the number of nodes (n) in the eigenfunction and the angular momentum (l) of the particle. It is known, for example that, $E \propto N^{-2}$, $N = n + l + 1$ for single electron atoms and ions and $E = (2n + l + 3/2)\hbar\omega$ for the three dimensional isotropic harmonic oscillator. Such formulae have utility in parameterizing nuclear collective motion and eigenvalues of

"effective potential" calculations used in solid state and atomic physics.

Figure 10 shows exact energy eigenvalues with dots and a dashed line connecting states of the same n and l but different s . The solid lines are predictions from the approximate formula*:

$$2) \quad \xi_{nl} = \left| \frac{2+\Delta}{2\Delta} \right|^{\frac{2+\Delta}{2\Delta}} \Delta^{1/\Delta} \sqrt{2} \left[l + \frac{1}{2} + \sqrt{\Delta+2} (n + \frac{1}{2}) \right]$$

$$\xi_{nl} \equiv \left| \epsilon_{nl} \right|^{\frac{2+\Delta}{2\Delta}} \quad \text{where } \epsilon \text{ is the energy eigenvalue in}$$

dimensionless units. See also column a, Table 3.

The ordinate on the figure is $\xi_{nl}^0 \equiv \frac{\xi_{nl}}{\xi_{01} - \xi_{\infty}}$ The abscissa

is $s = \frac{2+\Delta}{2+\Delta}$

This approximate formula does well for states with $-2.0 \leq s \leq 1.0$

($-1.0 \leq s \leq 2.0$). The region of $1.0 \leq s \leq 2.0$ is not well covered by the approximate eigenvalue formula.

The WKBJ or "phase integral" method is very helpful for understanding this region. The integral to be done is:

$$3) \quad 2\pi (n + \frac{1}{2}) = \oint \sqrt{\epsilon - r^{\Delta} - \left(\frac{l + \frac{1}{2}}{r} \right)^2} dr$$

Again energy and distance are in dimensionless units. For specific values of s this integral can be done in terms of either circular or elliptic functions. We have discovered a way to integrate (3) in terms of an infinite series of beta functions (converging for $W \equiv \frac{l + \frac{1}{2}}{\xi} < 1$) for any s . From this infinite series we have extracted two simple approximation formulae accurate to $\mathcal{O}(W^2)$ and $\mathcal{O}(W^3)$ respectively.

Table 3 compares the calculation of ξ for the case of $s = 4$, $n = 0, 2$, and 7 for a number of different formulae.

*The first use of this formula that we are aware of was by W. Swiatecki in a lecture at the Niels Bohr Institute in Copenhagen.

Figure 10

Table 3

s = 4

n ℓ	(a)	(b)	(c)	(d)	exact
00	2.780	2.696	2.664	2.669	2.722
10	6.728	6.290	6.277	6.278	6.304
20	10.676	9.885	9.876	9.876	9.893
30	14.625	13.479	13.473	13.473	13.485
40	18.573	17.073	17.069	17.069	17.078
50	22.521	20.668	20.664	20.664	20.672
02	6.004	6.290	5.930	5.960	5.975
12	9.952	9.885	9.863	9.670	9.684
22	13.900	13.479	13.319		13.333
32	17.848	17.073	16.947		16.958
42	21.797	20.668	20.564	20.565	20.572
52	25.745	24.262	24.174		24.181
07	14.063	15.276	13.892		14.050
17	18.011	18.871	17.789		17.872
27	21.959	22.465	21.573		21.623
37	25.904	26.060	25.299		25.332
47	29.856	29.654	28.990		29.013
57	33.804	33.248	32.659		32.676

Column a $\xi_a = 1.611854897 (\ell + \frac{1}{2} + \sqrt{6} (n + \frac{1}{2}))$ See equation 2

Column b $\xi_b = 1.797210352 (2n + \ell + \frac{3}{2})$

Column c $\xi_c = \xi_b (\frac{1}{2} + \frac{1}{2} \sqrt{1 - K\zeta^2})$

$K = .178828281, \quad \zeta = (\ell + \frac{1}{2}) / (2n + \ell + \frac{3}{2})$

In column d: values obtained by numerically integrating equation 3

In the last column are exact Quantum Mechanical values.

Of the approximation formulae c which is $O(W^3)$ is the best overall. a is best for $\ell \gg n$.

Publications and Abstracts

- (1) E3 Isomers of ^{93}Y and ^{101}Ag , V. R. Casella, J. D. Knight, and R. A. Naumann, Nucl. Phys. A239, 83 (1975).
- (2) The Radioactive Decay of ^{170}Re , L. Sterna, P. E. Haustein, E. J. Ansaldi, R. A. Naumann, and T. E. Ward, Phys. Letts. 53B, 432 (1975).
- (3) Temperature Dependence of the Electric Quadrupole Interaction: Cd and Ta in Ti, E. N. Kaufmann, P. Raghavan, R. S. Raghavan, K. Krien, and R. A. Naumann, Phys. Stat. Sol. 63B, 719 (1974).
- (4) Nuclear Quadrupole Interaction of ^{111}Cd in Zn, P. Raghavan, R. S. Raghavan, E. N. Kaufmann, K. Krien, and R. A. Naumann, J. of Phys. F4, 180 (1974).
- (5) Chemical Effects in the Capture of Negative Muons, L. F. Mausner, R. A. Naumann, J. A. Monard, and S. N. Kaplan, Phys. Letts. 56B, 145 (1975).
- (6) Preferred Sites of Impurities Implanted in Be: Lattice Location and Quadrupole Interactions, E. N. Kaufmann, P. Raghavan, R. S. Raghavan, E. J. Ansaldi, and R. A. Naumann, Phys. Rev. Letts. 34, 1558 (1975).
- (7) A Liquid Target System for the On-Line Production and Mass Separation of Noble Gases, E. J. Ansaldi, G. T. Garvey, J. M. Lind, F. W. Loeser, and R. A. Naumann, Nucl. Instr. & Meth. 125, 429 (1975).
- (8) A Study of Weak Coupling in ^{101}Rh , ^{105}Ag , ^{107}Ag , Bull. Am. Phys. Soc. 20, 73 (1975).
- ✓ (9) E3 Isomer of ^{101}Ag , V. R. Casella, J. D. Knight, and R. A. Naumann, Bull. Am. Phys. Soc. 20, 73 (1975).
- ✗ (10) Chemical Effects in the Atomic Capture of Negative Muons, L. F. Mausner, R. A. Naumann, J. A. Monard, and S. N. Kaplan, Bull. Am. Phys. Soc. 20, 91 (1975).