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Morton Kaplan
Principal Investigator

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Contract AT(11-1)3246

(U. S. Atomic Energy Commission--Carnegie-Mellon University)

Annual Report: July, 1972

The program of research in nuclear chemistry supported by Contract AT(11-1)3246 [formerly AT(30-1)4177] continues to be effective and stimulating. In the past year, most of our effort has gone into hyperfine interaction studies, making full use of our facilities for carrying out Mössbauer effect experiments under a selection of controlled environmental conditions. We have also obtained some useful results from the technique of perturbing the angular correlation of cascade nuclear gamma rays, and considerable success has been achieved in experiments with polarized radioactive nuclei. The general orientation and motivation of the research program have been described in detail in previous annual reports (see particularly NYO-4177-103, Annual Report July 1971), as has the development and operation of the experimental apparatus and equipment. No major additions or alterations in facilities have been made this year, although minor improvements in various experimental systems have been incorporated in the course of the work.

Perhaps the most satisfying of this year's conclusions has been in the completion of an extensive investigation into the nuclear and ionic interactions of Fe^{3+} ions in crystals of ferric chloride hexahydrate, $\text{FeCl}_3 \cdot 6\text{H}_2\text{O}$. This work has been carried out over a period of several years, and reports have been made as the study progressed. The experiments have produced the discovery of a magnetically ordered (antiferromagnetic) phase at very low temperatures, the first direct observations of how an induced magnetic hyperfine field at Fe nuclei varies with the angle between crystal axes and external polarizing field, and detailed measurements of the magnetic inter-

actions in applied fields for both the ordered and paramagnetic states of the crystal. These results, together with a highly successful analysis and interpretation using molecular field theory, constitute the Ph.D. thesis of Thomas X. Carroll under the title, Mössbauer Effect Studies of Magnetic Interactions in Ferric Chloride Hexahydrate".

Substantial progress has been made in the ^{151}Eu Mössbauer experiments with europium hexammine, $\text{Eu}(\text{NH}_3)_6$. Many of the technical problems associated with the preparation and handling of the unstable $\text{Eu}(\text{II})$ compound have been solved, and reliable data have been obtained for the temperature and field dependence of isomer shifts, recoil-free fractions, and line broadening due to paramagnetic relaxation effects.

In the first part of the contract year, several series of experiments were carried out using the gamma-gamma angular correlation technique to survey the emitted radiation patterns for several species in solution. Using ^{111}Ag as the radioactive nucleus in a number of different molecular types, preliminary results have indicated an unexpected effect in which the observed anisotropy changes slowly with time over many days as though a chemical or physical reaction were taking place.

During most of the present year, the principal investigator, Dr. Morton Kaplan, was in residence as a Visiting Professor in the Department of Physics, Clarendon Laboratory, University of Oxford. Working as a guest collaborator in the Nuclear Orientation Group of Dr. N. J. Stone, he initiated and successfully performed experiments to measure magnetic moments of radioactive nuclei and internal hyperfine fields by means of the anisotropies in gamma-ray emission from polarized nuclei. These studies are closely related to current and past investigations supported by the AEC, as Nuclear Orientation, Mössbauer

Effect, and Perturbed Angular Correlations all depend on the nuclear hyperfine interaction for their great potential in yielding information.

In addition to the principal investigator, scientific personnel include Drs. Frederick T. Parker and Mark B. Perkal, Research Associates, and Mr. Thomas X. Carroll, Project Scientist (graduate student). Dr. Perkal resigned from the program in January to take up an industrial position with a pharmaceutical company. He has the responsibility of organizing and setting up a new radiochemistry laboratory. Mr. Carroll has completed his thesis research in the program, and this spring has successfully submitted his Ph.D. dissertation based upon the research supported by the AEC contract. Dr. Carroll has accepted a postdoctoral appointment with Professor T. D. Thomas at Oregon State University Radiation Center, to continue and broaden his training as a nuclear chemist.

In the succeeding pages, some of the specific research studies are discussed in more detail and recent results are presented. A number of scientific papers based upon the work are in various stages of publication, submission, and writing.

I. Mössbauer Effect Studies of Magnetic Interactions in $\text{FeCl}_3 \cdot 6\text{H}_2\text{O}$

A. Detection of Spontaneous Magnetic Ordering.

Several previous investigations of the ^{57}Fe Mössbauer effect in $\text{FeCl}_3 \cdot 6\text{H}_2\text{O}$ have shown a complicated dependence of the quadrupole-split doublet on temperature and applied magnetic fields (e.g. previous annual reports, particularly July 1971 and July 1970). As part of a detailed investigation into the nature of the interactions, we have carried out Mössbauer measurements at temperatures below 4.2 K using a cryostat immersed in a pumped liquid helium bath. The source of 14.4 keV γ -rays was 10 mCi ^{57}Co in Cu, which gave a single-line unbroadened resonance at temperatures as low as 1.16 K, when run against a room temperature, single-line absorber of $\text{Na}_4\text{Fe}(\text{CN})_6 \cdot 10\text{H}_2\text{O}$. (Several early experiments using a ^{57}Co -in-Pd source showed the existence of magnetic splitting in the source at 4.2 K and below). The resonant absorber was polycrystalline $\text{FeCl}_3 \cdot 6\text{H}_2\text{O}$. Both source and absorber were in thermal equilibrium with the helium bath, whose temperature was controlled to 0.01 K by regulating the pumping speed. Temperatures were measured by He vapor pressure thermometry. Mössbauer spectra were taken with an automatic velocity spectrometer and stored in a multichannel analyzer.

An immediate result of these experiments was the appearance of magnetic hyperfine structure in the Mössbauer spectra at temperatures below 1.46 K, reflecting the onset of spontaneous magnetic ordering in the $\text{FeCl}_3 \cdot 6\text{H}_2\text{O}$ sample. In the table below, we have listed as functions of temperature, the splittings between the outer lines in the spectra, the corresponding magnitudes of the magnetic hyperfine fields, and the linewidths (FWHM) of the three pairs of resonance lines.

Table I. Magnetic Splitting, Internal Fields, and Linewidths
(FWHM) of Polycrystalline $\text{FeCl}_3 \cdot 6\text{H}_2\text{O}$ at Several
Temperatures below T_c .

T °K	Splitting (mm/sec)	H_{int} (kgauss)	$\Gamma(1, 6; 2, 5; 3, 4)$ (mm/sec)
1.46	0	0	--
1.43	6.0 ± 0.2	186 ± 6	(1.4 ; 0.8 ; 0.4)
1.34	9.95 ± 0.05	308 ± 2	(1.16; 0.77; 0.6)
1.29	11.26 ± 0.05	348 ± 2	(0.56; 0.47; 0.39)
1.16	12.79 ± 0.05	396 ± 2	(0.43; 0.34; 0.34)

Three main features emerge from our data:

(1) The 4.2 K spectrum is a quadrupole doublet (splitting $QS = -0.89$ mm/sec), with the more-negative velocity peak slightly broader and less intense than the positive velocity peak. However, this asymmetry is no longer present at 1.57 K. This behavior has been explained as resulting from temperature dependent spin-spin relaxation effects, consistent with a positive sign for the zero-field splitting parameter (D) of the ground 6S state of the Fe^{3+} ion, and the assumption that the electric field gradient (EFG) at the ^{57}Fe nucleus is negative.

(2) The rapid development of magnetic hyperfine structure in the spectra with decreasing temperature strongly demonstrates a transition to a magnetically ordered state. A simple extrapolation of the measured magnetic hyperfine field to zero yields a critical temperature

$$T_c = 1.46 \pm 0.01 \text{ K.}$$

A much longer extrapolation to zero temperature indicates a saturation hyperfine field of about 500 kG. Detailed studies in external magnetic fields show that $\text{FeCl}_3 \cdot 6\text{H}_2\text{O}$ orders antiferromagnetically.

(3) The well-resolved spectrum at 1.16 K yields an apparent quadrupole splitting $QS = + 0.35$ mm/sec. Comparing this value with the quadrupole splitting in the paramagnetic state, we find that the magnetic hyperfine field in the ordered state is oriented at an angle of 73 deg to the major axis of the EFG. If the magnetic anisotropy arises primarily from the crystal field, one expects an approximately transverse ordering, since the lowest lying Kramers doublet for $D > 0$ is $|\pm 1/2\rangle$ and is characterized by $g_{\perp} = 6$, $g_{\parallel} = 2$. That is, there is an "easy plane" of magnetization perpendicular to the symmetry axis (very likely the principal axis of the EFG).

The Mössbauer spectra taken below T_c exhibit considerable line broadening which decreases as the sample is cooled farther below T_c . While spin fluctuations may play some role in such broadening, we believe that the major effect is due to slight temperature variations with time during the runs. Although the temperature was held constant to 0.01 K, a greater degree of stability is required in the region where the internal field is changing rapidly with temperature. In fact, at 1.43 K, stability of 0.001 K would be needed to prevent the positions of the outer lines in the spectra from shifting more than 0.05 mm/sec.

B. Influence of Applied Fields on the Magnetic Properties of the Ordered State.

The anomalous effects of external magnetic fields on the Mössbauer spectra of polycrystalline $\text{FeCl}_3 \cdot 6\text{H}_2\text{O}$ at 77 K and 298 K (Annual Report, July 1970) and the observation of spontaneous magnetic ordering in this salt at 1.46 K imply that externally applied magnetic fields would be useful in studying the details of the magnetically ordered state. Experiments were carried out at $T = 1.16$ K with a single crystal sample of $\text{FeCl}_3 \cdot 6\text{H}_2\text{O}$ in applied fields from 0 to 23.7 kgauss. It is convenient to consider the Mössbauer results in three groups: The external field applied along the crystallographic "b" axis, and covering the range 0 to 7 kilogauss; the external field along "b" at higher fields (10-23.7 kgauss); and finally, application of the external field along the crystallographic "a" axis.

With the magnetic field along "b", the Mössbauer data show a strong and complicated dependence on the magnitude of the applied field. As the field is increased in the range from 0 to 3 kG, each of the six resonance absorption lines splits into a doublet, so that it appears that the total spectrum now consists of two sets of superimposed hyperfine spectra, the overall splitting of one set (A) increasing and of the other set (B) decreasing with applied field. Since the hyperfine fields corresponding to the two separate splittings differ by much more than the magnitude of the applied fields in each case, the source of the "twelve line spectra" must be from the interaction of the applied field with the ionic spins. As the external field is increased further, the trend towards increasing splitting of set A reverses, and now both six line patterns decrease in overall splitting, with set B decreasing faster than set A. At 5 kG the individual lines are considerably overlapped

and the spectra are poorly resolved. At 6 kG, the center of the spectrum is very intense, implying that one hyperfine pattern is near total collapse. Between 6 and 7 kG there is again a striking change leading to a single six-line pattern at 7 kG with an overall splitting only one-third that of the splitting in zero field. The spectra do not indicate a change from an antiferromagnetic state to a spin-flopped state, which should be a very sharp transition with applied field. Rather, since the anticipated molecular fields and the applied field are of comparable magnitude, it would appear reasonable that a gradual change from an antiferromagnetic state to a paramagnetic state is being induced by the external field.

This explanation is supported by the data at higher fields along the "b" axis. Above 10 kG, the trend of decreasing splitting with increasing field is reversed, and $\text{FeCl}_3 \cdot 6\text{H}_2\text{O}$ behaves as a paramagnet, showing no evidence of two unique sets of spins which were present at low fields. The hyperfine splitting in the Mössbauer spectra now increases with increasing field, exhibiting a corresponding internal hyperfine field of about 500 kG when the applied field is 23.7 kG. The saturation hyperfine field appears to be about 600 kG. Thus it would seem from our results that a metamagnetic transition occurs at 6-7 kG applied field, inducing an antiferromagnetic-to-paramagnetic transition.

Mössbauer spectra taken with the external field applied along the crystallographic "a" axis (perpendicular to "b") are completely different in behavior. The six line spectrum in zero field does not split further in applied fields, and the only effect of the external field is to cause only a small decrease in overall splitting and small changes in the intensities of the lines. These

small effects arise from rotation of the axis of ordering from perpendicular to the applied field (antiferromagnetic) to parallel (paramagnetic). Thus, these spectra serve to establish that in zero applied field the spins are antiferromagnetically ordered along the b-axis of the crystal, perpendicular to the a-axis.

The results presented here are qualitatively consistent with the predictions of a two sublattice molecular field model for an antiferromagnet. Detailed calculations carried out with this model reproduce the observed development of unique sets of sublattice spins and hyperfine fields, the expansion and collapse of the two sets of spectra, and the transition to a paramagnetic state. Because of the low Néel temperature and consequently small molecular fields in $\text{FeCl}_3 \cdot 6\text{H}_2\text{O}$, the Mössbauer effect has proven to be a very sensitive probe of the antiferromagnetic-paramagnetic transition.

C. The Paramagnetic State in External Fields.

A study of the angular variation of the effects of a large applied magnetic field on the Mössbauer spectra of a single crystal was made to determine the orientation of the crystal field Z (D) axis in $\text{FeCl}_3 \cdot 6\text{H}_2\text{O}$. It is a property of the axial crystal field term (in the spin Hamiltonian) that, if D is positive, a maximum magnetization or induced hyperfine splitting is attained when the applied field is in the " $g_{\perp}$ plane". At a temperature of 4.2 K with an applied field of 23.7 kilogauss in the plane of the crystal (the crystallographic a-b plane), spectra were recorded as the crystal was rotated in the plane and a maximum hyperfine splitting was found when the external field was parallel to the b-axis. This implies that the Z-axis is perpendicular to b and in the a-c plane. It would be expected to be at an

angle of 40° to c and 60° to a , if it coincides with the Cl-Fe-Cl direction in $\text{FeCl}_3 \cdot 6\text{H}_2\text{O}$, and this is a realistic suggestion.

To explore the magnitudes of the crystal field splitting term and the hyperfine field constant, sets of Mössbauer spectra were taken keeping the applied field at a known fixed angle to Z (90°), and measuring the variation of hyperfine splitting with applied field. These runs were done at two different temperatures, 4.2 and 1.55 K, (both in the paramagnetic region) with the external field parallel to the crystalline b -axis. It was hoped that these results could be matched with calculated magnetization curves, and from the comparison the "best fit" values of the two parameters D and H_{sat} could be found. This proved not to be the case, as the experimentally observed splittings increased almost linearly with external field, whereas the theoretical curves exhibited too much curvature for any choice of the two parameters.

Only by taking explicit account of the exchange interactions between neighboring Fe^{3+} ions, was it possible to obtain good agreement between theory and experiment. Since we know that $\text{FeCl}_3 \cdot 6\text{H}_2\text{O}$ spontaneously orders antiferromagnetically at 1.46 K, it seems quite reasonable to suppose that (antiferromagnetic) exchange fields will be of importance. For the purpose of analyzing our results, it is most convenient to use the molecular field theory, which allows us to treat each spin as being in an effective magnetic field composed of the external field and a hypothetical exchange field. Exchange field effects are treated here as being independent of temperature; that is, if an exchange field can be thought of as proportional to the degree of polarization below T_N (the ordering temperature), then an equivalent exchange field exists when the spins are externally polarized above T_N . This procedure leads to the conclusion that the difference between the field at the ion and the

external field is proportional to the magnetization. (The exchange correction is of the same form as that for demagnetizing fields, but may be much larger.) The resultant effect of the antiferromagnetic exchange is to suppress the magnitude of the observed hyperfine splitting and remove much of the observed hyperfine splitting and remove much of the (saturation) curvature in the computed curves of internal field vs. applied field. Comparison of theory with experiment now yielded excellent agreement with the values:

Crystal field splitting parameter, $D/k = 2.0 \pm 0.5^\circ\text{K}$;

Saturation hyperfine field, $H_{\text{sat}} = 600 \pm 10 \text{ kG}$;

Antiferromagnetic exchange field, $(N_1 + N_2) = 20.4 \pm 1.0 \text{ kG}$.

It should be noted that the success of this straightforward application of molecular field theory is only possible because the external field was applied in a direction of "easy magnetization". That is why the experiments were performed with H along the b -axis of the crystal. For other configurations, the interpretation becomes more complex, and such experiments and their analyses will be described at a later time.

II. Investigation of $\text{Eu}(\text{NH}_3)_6$ Using Mössbauer Resonance in ^{151}Eu .

For the last few years, we have had a strong interest in the hyperfine interactions and relaxation effects in compounds of divalent Eu. The Eu^{2+} ion has the electronic configuration $4f^7$, corresponding to a half-filled shell and no net orbital angular momentum. The resulting S-state ion has spin $7/2$, and these two characteristics (S-state and high spin) lead to the unique properties we wish to explore.

In the past year we have continued our experimental work with europium hexammine, $\text{Eu}(\text{NH}_3)_6$, begun the year before. It is, apparently quite difficult to synthesize and maintain pure samples, free of oxide contamination, and considerable effort has been devoted to solving this problem. Even under an inert atmosphere in a sealed glove box, one must take great care in the reaction of Eu metal with liquid NH_3 , and the product obtained decomposes readily if allowed to warm up or come in contact with air.

With relatively pure samples and a newly built dewar insert for variable temperature operation, we have obtained some very good ^{151}Eu resonance data in $\text{Eu}(\text{NH}_3)_6$. Spectra were recorded over the temperature range 1-77 K at roughly 8 deg intervals in order to accurately determine the temperature dependences of the recoil-free fraction, the linewidth, and the isomer shift. In this temperature range, the recoil-free fraction (proportional to the resonance area) changes quite strongly with temperature, and the experimental data can be fitted very well with theory, yielding a Debye temperature $\theta = 43.0$ K for the $\text{Eu}(\text{NH}_3)_6$ lattice. This rather low Debye temperature, corresponding to a very soft lattice, accounts for the fact that the Mössbauer resonance is quite small at liquid nitrogen temperature, and virtually non-existent at higher temperatures. It also demonstrates that a small amount

of EuO impurity, with a Debye temperature of 240 K, can easily lead to erroneous results.

In the presence of a strong magnetic field, the ^{151}Eu Mössbauer spectra break up into a multiple line pattern characteristic of an induced hyperfine field. In Table II below, we present some results obtained for $\text{Eu}(\text{NH}_3)_6$ at $T = 1.2$ K, making use of a Mössbauer spectrometer coupled to a high-field superconducting magnet.

Table II. Internal Hyperfine Fields, Isomer Shifts, and Linewidths (FWHM) of $\text{Eu}(\text{NH}_3)_6$ at 1.3 K in Several Applied Fields

H_{ext} (kgauss)	H_{int} (kgauss)	Isomer Shift (mm/sec)	FWHM (mm/sec)
22	278.7 (1.4)	-12.87	3.28
40	268.8 (1.5)	-13.02	3.48
50	264.9 (1.7)	-12.84	4.00
60	249.9 (2.0)	-12.88	4.04
70	239.9 (2.2)	-12.99	4.40

Although the magnet was designed to produce a maximum field of 60 kG at 4.2 K, it was found to operate quite well at 70 kG when the ambient temperature was lowered to 1.2 K. This is because of the strong dependence of critical current on temperature for NbT: superconductor. The data in Table II yield a saturation hyperfine field about 312 kG, which is in excellent agreement with that expected for a pure $S = 7/2$ ion.

Further experiments and analyses of $\text{Eu}(\text{NH}_3)_6$ data are continuing, as are theoretical calculations of relaxation spectra.

III. Angular Correlation of Cascade Gamma Rays in the Decay of ^{111}Ag .

Using the apparatus described in detail in the last Annual Report (NYO-4177-103, July 1971), we have performed a number of experiments to determine the influence of molecular identity on the angular correlation of the 95-247 keV gamma ray cascade in ^{111}Cd from the decay of 7.5 d ^{111}Ag . Preliminary data was obtained for samples of ^{111}Ag as AgNO_3 in aqueous solution, and in the presence of NH_3 , DNA, α -chymotrypsin, and carbonic anhydrase. Each of these latter molecular species would be expected to form a tight complex with Ag ions and provide a different immediate environment. As a means of monitoring experimental reproducibility, samples of aqueous AgNO_3 were remeasured every few days over the period of several months of study. It was found that the anisotropy of the angular correlation changed systematically with time, going from the full unperturbed theoretical value, in a fresh sample, to much smaller anisotropies in aged samples. This unexpected effect might be explainable by slow adsorption of Ag ions onto the walls of the sample holder, or by the precipitation of colloidal metallic Ag, but no clear evidence for such processes was found and attempts had been made in sample preparation to avoid just such problems. However, until this behavior is well understood, or eliminated, the observed differences found for the other Ag-complexes cannot be given serious consideration. The experimental apparatus itself proved to be very reliable and stable over long periods, provided that the ambient temperature in the laboratory was controlled rather carefully.

This work has been temporarily suspended in mid-year as a result of a personnel change, but will be taken up again in the future.

IV. Nuclear Orientation and Nuclear Magnetic Resonance in Polarized Nuclei.

A. Hyperfine Field at As nuclei in Fe and the Magnetic Moment of ^{74}As .

The combination of a resonance technique with signal detection by nuclear radiation permits the study of nuclear properties with both high sensitivity and high accuracy. We have carried out a series of experiments in which ^{74}As nuclei were polarized at very low temperatures via the hyperfine interaction in ferromagnetic Fe metal, resulting in strongly anisotropic emission of the nuclear decay gamma rays. By applying a radio-frequency field at the proper frequency to the polarized nuclei, transitions were induced between the nuclear Zeeman levels, thereby destroying the nuclear polarization and altering the distribution of emitted radiation. The NMR frequency is thus detected from a change in counting rates and can be accurately measured. This work represents the first successful orientation and resonance of As nuclei in thermal equilibrium, and has yielded significant new results for both the nuclear ground state properties and the interaction with the Fe host.

The nucleus ^{74}As was of particular interest for investigation because its magnetic moment was unknown and a simple shell model description of the odd nucleons gives a ground state configuration $(\pi f_{5/2})^1 (v g_{9/2})^1$, in good agreement with the known spin and parity, 2^- . The decay of 17.9 day ^{74}As proceeds both by β^- emission to ^{74}Se and by electron capture and β^+ emission to ^{74}Ge . The corresponding β -decays to the first excited 2^+ states in ^{74}Se and ^{74}Ge are each first-forbidden with the similar log ft values of 7.6 and 6.9, respectively. The succeeding de-excitation γ rays to the 0^+ ground states both have E2 character and differ in energy by only 39 keV. Thus by using high resolution Ge(Li) detectors to monitor the 596 and 635 keV γ rays independently in the same experiment, we expected to observe any major

differences which might exist in the angular momenta of the electron-neutrino fields associated with the β decays to ^{74}Se and ^{74}Ge .

Sources were prepared by electroplating carrier-free ^{74}As radioactivity onto high purity Fe, followed by diffusion in hydrogen at high temperatures to incorporate the As atoms into the Fe lattice. The $^{74}\text{As}/\text{Fe}$ sources were soldered to the Cu cold finger of an adiabatic demagnetization cryostat, and cooled to 0.014 K by thermal contact with a demagnetized chrome alum reservoir. Sample temperatures were measured by monitoring the gamma-ray anisotropy from ^{60}Co using $^{60}\text{Co}/\text{Fe}$ samples soldered adjacent to the $^{74}\text{As}/\text{Fe}$ foils.

Extensive data were collected for the gamma-ray anisotropies as a function of temperature, and the data for the 596 keV γ ray in ^{74}Ge and the 635 keV γ ray in ^{74}Se were analyzed independently. No significant difference was found to exist between the results for these two gamma rays, and hence the average angular momenta of the emitted leptons must be about the same in the two preceding β decay modes. As the $(2^-) \rightarrow (2^+)$ β decay of ^{74}As is first forbidden, there can in general be a mixture of angular momentum multipoles associated with the electron-neutrino field. Comparison of our nuclear orientation results with theoretical calculations demonstrates unambiguously the predominance of $j_\beta = 0$ in the β decays of ^{74}As to the 2^+ states in ^{74}Ge and ^{74}Se . The experimental data are in excellent agreement with a β decay mixing ratio $\delta^2 = 0.00$ (pure $j_\beta = 0$) and an upper limit $\delta^2 = 0.05$ can be set for the maximum admixture of $j_\beta = 1$.

The nuclear resonance experiments were carried out with thin ($2\mu\text{m}$) $^{74}\text{As}/\text{Fe}$ foils at a sample temperature of approximately 0.02 K. In a polarizing field of 1.79 kG, a strong NMR signal was detected at a frequency

$\nu = 209.88 \pm 0.15$ MHz, and increasing the polarizing field to 5.15 kG resulted in a new resonance frequency at 211.95 MHz. The observed increase in resonance frequency with increase in polarizing field uniquely determines the sign of the internal field at As nuclei in Fe as positive. Hence the applied polarizing field must be added to the magnitude of the internal hyperfine field in As/Fe to derive the nuclear magnetic moment of ^{74}As from the observed NMR frequency. Koi has recently performed an accurate measurement of the NMR frequency for stable ^{75}As in Fe, using a spin echo technique, and obtained the result $\nu = 250.8 \pm 0.2$ MHz at 4.2 K. Combining this value with the known magnetic moment and spin of ^{75}As , we find

$$H = 342.9 \pm 0.3 \text{ kG}$$

for the internal field at As nuclei in Fe. From our own resonance results and the above hyperfine field, we obtain for the nuclear magnetic moment of ^{74}As

$$|\mu| = 1.597 \pm 0.003 \text{ n.m.}$$

including diamagnetic correction. The uncertainty in the magnetic moment reflects primarily the assigned errors in the hyperfine field and the NMR frequency.

We have collected in Table III below the measured magnetic moments of several nuclei closely related to ^{74}As .

Table III. Magnetic Moments of Odd-Odd Nuclei with $f_{5/2}$ protons and $g_{9/2}$ neutrons coupled to $I = 2$.

Nucleus	Configuration	μ (n.m.)
$^{74}_{33}\text{As}$	$(\pi f_{5/2})^1 (\nu g_{9/2})^1$	(-) 1.597 (3)
$^{76}_{33}\text{As}$	$(\pi f_{5/2})^1 (\nu g_{9/2})^3$	-0.906 (5)
$^{84}_{37}\text{Rb}$	$(\pi f_{5/2})^{-1} (\nu g_{9/2})^{-3}$	-1.32 (2)
$^{86}_{37}\text{Rb}$	$(\pi f_{5/2})^{-1} (\nu g_{9/2})^{-1}$	-1.6915(14)

Although our experiment does not determine the sign of μ , it is presumably negative, as deduced by comparison with the other nuclei. The close agreement between the magnetic moments of ^{74}As , with two odd nucleons, and ^{86}Rb with two odd holes in the corresponding subshells, is rather striking. The other nuclei in Table III do not exhibit such a simple relationship.

B. Studies of Oriented ^{206}Bi and ^{207}Bi in Ni and Fe.

Nuclear Orientation experiments have been performed on the isotopes ^{206}Bi and ^{207}Bi , each independently melted into host lattices of Ni and Fe. The system Bi/Ni is metallurgically stable, and samples exhibited a high degree of reproducibility. On the other hand, Bi is of very limited solubility in Fe, and good samples were much more difficult to prepare.

Gamma ray anisotropies were measured as a function of temperature for 11 transitions in ^{206}Pb and 3 transitions in ^{207}Pb . From the known magnetic moment of ^{206}Bi , and the anisotropy data of the pure El, 1.720 MeV gamma ray in ^{206}Pb , we have derived the hyperfine field at Bi nuclei in Ni as $H_{\text{hf}} =$

390 ± 15 kG. The mixing ratio of the 497 keV gamma ray in ^{206}Pb is determined as $\delta(E2/M1) = -0.09 \pm 0.02$. The data for the other gamma rays and the results obtained in Fe are currently being analyzed. From the measured hyperfine field of ^{206}Bi in Ni, we can analyze the $^{207}\text{Bi}/\text{Ni}$ data to derive the nuclear magnetic moment of ^{207}Bi and also investigate the attenuation of gamma ray anisotropy through depolarization of the 0.80 sec, $13/2$ state in ^{207}Pb .