List of author's publications and reports


4. Internal hyperfine field on arsenic in gadolinium; International conference on hyperfine interactions studied in nuclear reactions and decay, Uppsala, Sweden, 1974.

5. g-factor of the 658 keV state in $^{110}$Cd - to be published.

6. Internal hyperfine field on arsenic in iron and gadolinium - to be published.

7. Hyperfine magnetic field on Hf in iron and nickel - to be published.

8. Hyperfine magnetic field on Pt in cobalt and nickel - to be published.
FIG. 4.10 PHOTOGRAPH OF THE ACTUAL SET UP.
The Internal Hyperfine Magnetic Fields on Arsenic in Cobalt and Nickel Hosts

A. K. Dhar, Bhupender Singh, Vikram Singh and H. S. Hans
The Internal Hyperfine Magnetic Fields on Arsenic in Cobalt and Nickel Hosts

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The hyperfine internal magnetic fields on arsenic nuclei in cobalt and nickel hosts have been measured by the integral reversed field method of perturbed angular correlation technique. The $^{5+}/2$ (121.1 keV) $^3/2$ (279.6 keV) $^3/2$ cascade in $^{75}$As was used for the directional correlation and rotation measurements. Using $g=0.36\pm0.04$ and $r=(4.67\pm0.43)\times10^{-10}$ sec for the 279.6 keV level of $^{75}$As, the hyperfine fields on arsenic in cobalt and nickel at room temperature have been found to be

$$H_{\alpha}^{\text{Co}}=+252\pm45 \text{ kOe},$$
$$H_{\alpha}^{\text{Ni}}=+121\pm20 \text{ kOe},$$

respectively. The hyperfine fields on arsenic in iron, cobalt and nickel hosts seem to be predominantly proportional to the effective host moments.

§ 1. Introduction

The recent investigations of Shirley and Westenberg and Watson and Freeman on hyperfine fields at nuclei embedded as dilute impurities in ferromagnets show some systematic trends. These hyperfine fields have been interpreted in terms of two major mechanisms, viz; core polarization and conduction electron polarization, but the interpretation has not been unique. This is partly due to the lack of available data on the hyperfine fields. Shirley et al. have tabulated the measured hyperfine fields at various nuclei in iron, cobalt, nickel hosts. The hyperfine field at arsenic in iron has been measured previously by Kol using nuclear magnetic resonance technique, but the fields at arsenic in cobalt and nickel are not known. The present paper deals with the measurements on these two fields.

The integral reversed field method of perturbed angular correlation technique has been used for the present purpose. The isotope used was $^{75}$Se whose partial decay scheme is shown in Fig. 1. The 121.1-279.6 keV cascade was used for measurements of the rotation of the angular correlation pattern.

§ 2. Source Preparation

The radioisotope $^{75}$Se was obtained from Bhabha Atomic Research Centre, Bombay, India, in the form of sodium seleno sulphate in neutral solution. For electroplating selenium on a ferromagnetic host, the source had to be brought in a proper chemical form. The following chemistry was done for this purpose. The neutral source solution was made acidic by adding a few drops of 3 N hydrochloric acid. Through this solution sulphur

* Note added in proof. The sign of the $H_{\alpha}$ was earlier deduced to be negative. Realizing the mistake in 'Rotation-sense convention' the sign of the field was found to be positive. This has resulted in lower values of the hyperfine fields because the polarizing field is now being subtracted from $H_{\alpha}$, instead of getting previously added to the $H_{\alpha}$ magnitude.
dioxide gas was passed to precipitate out all the selenium (reddish brown precipitate). A few drops of alcohol were added to it for coagulation and the solution was centrifuged. Discarding the supernatant liquid the residue was washed with alcohol and dissolved in minimum amount of aqua regia. The solution thus got was evaporated to dryness. The dried residue was treated with a few drops of concentrated hydrobromic acid and the solution was evaporated gently on a water bath so that the selenium is not lost, as it is volatile in hydrobromic acid. This dried mass was dissolved in 0.1N hydrobromic acid and used as such for the directional correlation work and for electroplating on cobalt, nickel and copper wires.

The selenium activity was electroplated from this solution on 1 cm length of 1 mm diameter spectroscopically pure cobalt, nickel and copper wires by passing 10 mA current for two hours. The anode in each case was a platinum wire. The electroplated portion of the wire was cut, washed with alcohol and water, dried and transferred to a quartz tube. The quartz tube was evacuated and filled with nitrogen and sealed. This tube was then kept at 100°C in a diffusion furnace for thirty hours. To ensure proper diffusion it was necessary to keep the furnace initially at low temperature for a long time because selenium has got a low melting point. The temperature of the furnace was then increased to 200°C and kept there for about sixty hours, after which it was raised to 350°C for five hours. The quartz tube was then taken out and heated in a direct flame for melting the wire. The quartz tube, now with the melted wire inside in the form of a button, was put in an annealing furnace. The initial temperature of this furnace was kept at 1500 K and 700 K for selenium-cobalt and selenium-nickel sources respectively. This tube was then kept at 100°C in a diffusion furnace for thirty hours. To ensure that the peaks did not shift, the counting period at each angle was made very small and the gates of intersection of the axes of the two crystals.

The counting rate being now sensitive to even small shifts in pulse heights, the counting period was kept at 0.01 sec. The coincidence counts were collected at seven angles between 90° and 180° at an interval of 15° each. A least squares fit of the data corrected for the random coincidences yields the following correlation coefficients after solid angle correction:

$$A_2 = -0.1486 \pm 0.0055$$
$$A_4 = 0.0477 \pm 0.0080$$

These coefficients have not been corrected for the interference from the 135.9-264.6 keV cascade. The lifetime of the 279.6 keV level being nearly $5 \times 10^{-11}$ sec it is reasonable to suspect a time dependent interaction attenuating the $A_2$ and $A_4$ coefficients of the 121.1-279.6 keV cascade. Since copper provides a matrix of cubic symmetry, the static and time dependent perturbations are expected to be absent in it. An angular correlation measurement of the 121.1-279.6 keV cascade was done with selenium-copper source in the same geometry as used in case of the liquid source. The least squares fit of the data of all the seven angles gives the correlation coefficients after correction for chance coincidences and geometry:

$$A_2 = -0.1460 \pm 0.0084$$
$$A_4 = 0.0281 \pm 0.0123$$

The angular correlation results for the 121.1-279.6 keV cascade do not differ strongly for the liquid selenium and selenium-copper sources, which indicates that the time dependent perturbations are absent for this cascade, i.e. $G_2=1$.

In order to measure the rotation of the angular correlation pattern in external magnetic field we need the correlation coefficients in the magnet...
geometry. The directional correlation measurement for the liquid source in this case yields:

\[
A_1 = -0.1002 \pm 0.0026 \\
A_2 = +0.0180 \pm 0.0035
\]

as the correlation coefficients uncorrected for geometry and scattering. These coefficients will be used in the next section for calculating the rotation of the angular correlation pattern.

Schardt and Welker,10 Kelly and Wiedenbeck,11 and van den Bold et al.12 have measured the directional correlation coefficients for the 121.1-279.6 keV cascade, which are much larger than our presently measured values. The reason for their large correlation coefficients is that they have been able to remove the interference of the 135.9-264.6 keV cascade, almost completely. In all our directional correlation measurements the interference of the 135.9-264.6 keV cascade in the 121.1-279.6 keV cascade could not be completely removed which has reduced the observed anisotropy. This is of no real trouble in the rotation measurements as the previous measurements10-12 have shown the 135.9-264.6 keV cascade to be nearly isotropic and further the lifetime of the 264.6 keV level (1.6 x 10^{-11} sec) is considerably shorter than that of the 279.6 keV level.

3.2 \(ar\) measurements

For the measurement of the hyperfine fields at arsenic in cobalt and nickel several sources of selenium-cobalt and selenium-nickel with different concentrations of selenium were used. As our selenium source obtained from BARC, India, was not completely carrier free, the concentration of selenium in selenium-cobalt and selenium-nickel alloys was checked by weighing the wire before and after electroplating; in each case the atomic concentration of selenium was found to be less than 0.2%.

Since the \(A_2\)-coefficient for the 121.1-279.6 keV cascade is nearly zero, the two detectors were kept at 135° with respect to each other. An external magnetic field of 7.5 kOe was used to polarize the internal fields in each alloy, normal to the plane of the two detectors. In order to avoid the effect of stray magnetic field both the photomultiplier tubes were shielded by several layers of nelson sheets, mu-metal shields and soft iron cylinders. The efficacy of the shielding was checked by measuring the counting rate in either detector with field up and field down. The change in counting rate was found to be within the statistical error. For measurement of \(ar\), the coincidence counts were collected for ten minutes in each field direction in a sequence of field up, down, down, up, down...... After correcting the coincidence counts for chance coincidences, the quantity \(R\) defined as

\[
R = \frac{C_{up}-C_{down}}{C_{up}+C_{down}}
\]

was calculated in each case; where \(C_{up}\) and \(C_{down}\) denote the true coincidences for field up and field down respectively.

From the measured value of \(R\), the value of \(ar\) in each case was calculated graphically by using the relation,

\[
R = \frac{4C_{2}G_{2}C_{2}}{1+(2G_{2})^{2}}
\]

where \(C_{2} = 3A_{2}(4 + A_{2})\). In order to calculate the effective magnetic fields at arsenic nuclei in cobalt and nickel from the measured values of \(ar\), the following relation was used:

\[
H_{\text{effective}} = \frac{g_{\mu}H_{z}}{C_{2}}
\]

where \(g = 0.36 \pm 0.04\) and \(\tau = (4.67 \pm 0.43) \times 10^{-11}\) sec are respectively the nuclear \(g\)-factor and lifetime of the 279.6 keV level of \(^{75}\)As, and \(\mu_{N} = 5.05 \times 10^{-24}\) erg gauss is the nuclear magneton. The values of the \(g\)-factor and lifetime taken above are the weighted averages of the previously measured values of the \(g\)-factor by Manning and Rogers,14 Agarwal and C.V.K. Baba14 and

<table>
<thead>
<tr>
<th>SOURCE</th>
<th>(ar)</th>
<th>(ar) rad</th>
<th>(H_{\text{effective}}) kOe</th>
</tr>
</thead>
<tbody>
<tr>
<td>As-Co sample I</td>
<td>-0.0542 ± 0.0087</td>
<td>0.205 ± 0.033</td>
<td>0.206 ± 0.027 (= 259.7 \pm 46.5)</td>
</tr>
<tr>
<td>As-Co sample II</td>
<td>-0.0555 ± 0.0112</td>
<td>0.213 ± 0.043</td>
<td>(= 259.7 \pm 46.5)</td>
</tr>
<tr>
<td>As-Ni sample I</td>
<td>-0.0288 ± 0.0038</td>
<td>0.097 ± 0.013</td>
<td>(= 259.7 \pm 46.5)</td>
</tr>
<tr>
<td>As-Ni sample II</td>
<td>-0.0330 ± 0.0050</td>
<td>0.112 ± 0.017</td>
<td>(= 259.7 \pm 46.5)</td>
</tr>
</tbody>
</table>
The effective magnetic fields acting at solute nuclei in a ferromagnetic host can be written as:

$$H_{\text{eff}} = H_{hf} + H_{\text{ext}} + (4\pi/3-D)M.$$  

Here $H_{hf}$ and $H_{\text{ext}}$ are the hyperfine field and the external applied field respectively. The last term in the above equation is the sum of Lorentz field and demagnetising field, and is very small in comparison to the first two terms. Using the value of $H_{\text{ext}} = 7.5$ kOe and neglecting the last term, the values of hyperfine fields were deduced to be:

- $H_{\text{co}} \text{(Room temperature)} = +252 \pm 45$ kOe
- $H_{\text{f}} \text{co} \text{(Room temperature)} = +121 \pm 20$ kOe.

Table I shows the summary of all our measurements. The value of $R$ did not differ for the two concentrations in each alloy. The sign of the hyperfine field in each case was found from the sense of the rotation of the angular correlation pattern.

§ 4. Discussion

Koi\textsuperscript{4) has measured the hyperfine field on arsenic in iron, $H_{p} = 339.1$ kOe at 4.2 K, using the nuclear magnetic resonance technique. The sign of the field is unknown in this measurement.

Since our present measurements yield positive hyperfine fields for arsenic-cobalt and arsenic-nickel alloys, we presume the sign of the field to be positive in arsenic-iron alloy also.

In Fig. 2, the hyperfine fields for arsenic in iron, cobalt and nickel have been plotted against the effective host magnetic moments, wherein the iron field has been corrected for temperature ($H_{\text{hf}}$ at room temperature is 0.97 times the field at 4.2 K).\textsuperscript{20} The plot shows that the hyperfine fields in case of arsenic are roughly proportional to the host moments, suggesting an inductive mechanism due to the host 3d electrons.

Not much data are available at present for the hyperfine fields in the region $30 < Z < 40$ ($Z$ = solute atomic number). Further measurements in this region will help to establish a clear picture of the origin of these fields.

The first two authors wish to express their sincere thanks to the Department of Atomic Energy (India) and the Council of Scientific and Industrial Research (India) for the grant of research fellowships.

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Magnetic Moment of the $3^-$, 1374-keV Level of $^{182}$W

Bhupender Singh, Ashok K. Dhar, Vikram Singh and H. S. Hans
Magnetic Moment of the $\frac{3}{2}^+$, 1374 keV Level of $^{182}$W

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The reversed field method in a time-integrated directional correlation measurement has been used to determine the magnetic moment of the $\frac{3}{2}^+$, 1374 keV level of $^{182}$W. An external magnetic field of 15 kOe has been used for the perturbation of the 179–152 keV cascade of $^{182}$W. The magnetic moment has been obtained to be $\mu(1374 \text{ keV}) = +1.74 \pm 0.16 \text{ n.m.}$

Our measured value of the magnetic moment establishes the 1374 keV level as a member of the $K=2$ rotation band of $^{182}$W.

§ 1. Introduction

The gamma-ray transitions in the decay of $^{182}$Ta to $^{182}$W (Fig. 1) have been the subject of a number of investigations (for references see ref. 1). The strongly deformed even-even nucleus $^{182}$W has got a ground state rotational band ($K=0$) and dense energy levels above 1 MeV, out of which there are two members considered to be of the $K=2$ even parity band and three members of the $K=2$ odd parity band. Bhattacharjee et al. have measured the magnetic moment of the two quasiparticle level at 1289 keV, which has been identified by Grigor'ev et al. as the lowest member of the $K=2$ rotational band. The character of the 1374 keV level has been partially interpreted by Grigor'ev et al. as a level entering in the rotational band constructed on the 1289 keV level. So it was thought worthwhile to measure the magnetic moment of the 1374 keV level and establish its character.

§ 2. Angular Correlation Measurements and the $g$-Factor of the 1374 keV Level

2.1 Angular correlation measurements

The 179–152 keV cascade populated in the decay of 115 day $^{182}$Ta is well suited for the magnetic moment measurement of the 1374 keV level of $^{182}$W. The integral reversed field method of perturbed angular correlation technique has been employed for the present measurements.

The radioactive source of $^{182}$Ta in the form of an oxalate complex in dilute sulphuric acid, got from Bhabha Atomic Research Centre, Bombay has been used for the angular correlation measurement of the 179–152 keV cascade. Conventional fast-slow coincidence technique was used for the measurement of the integral coincidence counting rate. The time resolution was 60 nsec. For detecting gamma-rays, two NaI(Tl) crystals of 1" dia. x 2" height mounted on RCA 6292 photomultiplier tubes were used. The resolution of both crystals

![Fig. 1. Partial decay scheme of $^{182}$Ta.](image-url)
was better than 10% for the 661 keV gamma ray of $^{137}$Cs. Figure 2 shows the singles and coincidence spectrum with the 152 keV gate. Since the 179 keV gamma ray is too weak to show up in singles spectrum, the gate for this gamma ray was chosen from the above coincidence spectrum at upper fraction of the coincidence peak. The 152 keV gamma ray was gated at the lower fraction of the 151 keV photopeak got in singles spectrum. The gates of both the gamma rays have also been shown in Fig. 2. The window width of both the discriminators selecting the two gamma rays was kept to be 1/8 volt. It was ensured at regular intervals that there was no shifting in the gates selected. With these gates, there was no cross-interference of the gamma rays in each other’s gate.

![Fig. 2. A) Low energy portion of the singles spectrum of $^{182}$Ta. B) Coincidence spectrum of $^{182}$W in coincidence with the gate at 152 keV gamma ray.]

An angular correlation measurement of the 179-152 keV cascade was performed using the liquid source in free geometry, in the absence of external magnetic field. The crystals were shielded laterally with graded lead cylinders and from the front with lead cones. These lead cylinders and cones were provided with graded tin and copper lining at the inner surfaces to avoid lead X-rays. A Compton shield was also used to avoid crystal-to-crystal scattering. The source, in the liquid form was symmetrically placed 7 cm from each crystal at the point of intersection of the axes of the two crystals. The source was centered to better than 0.5% variation in the singles rate of the movable detector at different angular positions with respect to the fixed one. The coincidence counts were collected at seven angles through 90° to 180° within 15° intervals. These coincidence counts were normalized for the both singles counts and corrected for random coincidences. A least squares fit of the data thus obtained was done by the usual method of Rose and the correlation coefficients were corrected for the finite angular resolution of the detectors using the calculated correction factors of Yates, which yielded the following coefficients:

$$A_2 = -0.129 \pm 0.007, \quad A_4 = 0.016 \pm 0.016.$$  

These coefficients were then corrected for the coincidences between the 152 keV and the coincident Compton background. This background was found to be 20% from coincidence spectra and was seen to be isotropic at 4 angles 90°, 120°, 150°, 180°. The corrected results are:

$$A_2 = -0.155 \pm 0.009, \quad A_4 = 0.019 \pm 0.019.$$  

El-Nesr et al. also have measured the directional correlation of the 179-152 keV cascade, using a different form of the source, viz., tantalum in hydrofluoric acid. They obtain:

$$A_2 = -0.150 \pm 0.010, \quad A_4 = 0.035 \pm 0.025,$$

as the solid angle and Compton-background corrected correlation coefficients for this cascade. The fact that the two sets of the coefficients are same within the experimental error, also indicates that there is no attenuation of the angular correlation due to perturbation. We assume therefore that the value of the integral attenuation coefficient $\gamma_1 = 1$.

A similar measurement of the directional correlation of the 179-152 keV cascades under identical conditions in the magnet geometry was also done. The angular correlation coefficients in this case are:

$$A_2 = -0.100 \pm 0.006, \quad A_4 = 0.007 \pm 0.005,$$

uncorrected for geometry, scattering or coincident Compton background. Only this value of $A_4$ was used to calculate the rotation $\gamma_{12}$ of this cascade in the magnetic field.

2.2 Precession measurements

The precession measurements were made at a counter separation of 135° which was the angle of maximum slope in the angular distribution of the 179-152 keV cascade. An external magnetic field of 15 kOe was applied perpendicular to the plane
of the two detectors and the coincidence counts were collected, reversing the field every 10 minutes, in the order of up, down, up, up, up, up, down, up, down, up, and so on. These coincidence counts were corrected for the chance contribution which was about 12%. The photomultiplier tubes were properly shielded magnetically and rotated to a position of minimum effect of field reversal on the multiplier gain. The resolving time of $2\tau_0 = 60$ nsec was verified to be constant by frequent checks. The quantity

$$R = 2 \frac{C_{up}-C_{down}}{C_{up}+C_{down}}$$

was calculated. Here $C_{up}$ and $C_{down}$ denote the true coincidence counts for the corresponding direction of the applied magnetic field. The procedure for obtaining $\alpha_1 \tau_1$ from this $R$ value is described somewhere else (see ref. 8). We assume that $A_1 = 0$ and $G_1 = 1$.

The measured value of $R = 0.042 \pm 0.003$ corresponds to the spin precession $\alpha_1 \tau_1 = 0.136 \pm 0.012$ rad. The reported half-life values for the 1374 keV level of $^{182}$W are $T_{1/2} = 2.25 \pm 0.08$ nsec from Bashandy and El-Nesr9 and $T_{1/2} = 2.4$ nsec from Bhattacherjee et al.10. More recently, $T_{1/2} = 1.70 \pm 0.05$ nsec by Abou-Leila and El-Nesr11 and $T_{1/2} = 1.75 \pm 0.05$ nsec by Bhattacherjee et al.11. All these half-life values agree well within their respective uncertainties.

The $g$-factor was deduced from the change in anisotropy due to the application of the external magnetic field. This $g$-factor corresponds to a magnetic moment

$$\mu = g_2 \hbar$$

which is very less in comparison to the half-life values of this level got by Bashandy and El-Nesr9' and Bhattacherjee et al.10.

§ 3. Discussion

The magnetic properties of a $K=2$ rotational band are described by two parameters, intrinsic $g_2$ and collective $g_4$. Grigor'ev et al.8 have deduced from measured $B(M1)$ values within the $K=2$ band of $^{182}$W that $|g_2 - g_4| = 0.50 \pm 0.11$. If calculations are carried out with the formula

$$\mu = \frac{K^2}{I+1} (g_2 - g_4) + Ig_4$$

using the presently measured value of the magnetic moment $\mu = 1.74 \pm 0.02$ n.m. of the 1374 keV level, we obtain the two values for $g_2$ as $g_2 = 0.41 \pm 0.09$ and $g_2 = 0.72 \pm 0.08$. Only the first value is compatible with the expected value of $g_2$ which should be of the same order as that of the first rotational level of $K=0$ band in $^{182}$W, obtained by Körner et al.,10 and Persson et al.11. This indicates that $g_{K=2} = g_{K=0} = 0.50 \pm 0.11$, which further results in $g_2 = 0.91 \pm 0.08$. Bhattacherjee et al.11 have also done a similar calculation in case of the 1289 keV level of the same isotope, which is the band head of the $K=2$ band in question. Whereas Bhattacherjee et al.11 have got a lower value of $g_2$ than the theoretically predicted value from the strong-coupling scheme, a comparison of our intrinsic $g$-factor $g_2$ for the 1374 keV level with their value indicates that strong-coupling scheme to hold in our case.

It becomes clear, therefore, that the 1374 keV level of $^{182}$W is also a member of the $K=2$ rotational band built on the 1289 keV level. The possibility of particle excitation mechanism is hence ruled out for the 1374 keV level.

Melting and Stary14 have estimated for the 1374 keV level of $^{182}$W a half life $T_{1/2} < 0.3$ nsec, which is very less in comparison to the half-life values of this level got by Bashandy and El-Nesr9 and Bhattacherjee et al.10 and Abou-Leila et al.11. If the half-life were so less one could not have observed as much rotation as observed in present experiment for the aforementioned cascade. The above consideration rules out the possibility of the half-life $T_{1/2} < 0.3$ nsec and supports the other half-life measurements.9-11

The authors wish to thank Shri S. C. Bedi for help in instrumentation. The authors (BS and AKD) sincerely thank the UGC, New Delhi and the D. A. E. Govt of India for grant of a Junior and Senior Research Fellowship respectively.

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Magnetic Moment of the 3\(^{-}\), 1374 keV Level of \(^{182}\)W

MAGNETIC MOMENT OF THE SECOND EXCITED STATE OF $^{160}$DY

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I. INTRODUCTION

It is generally assumed that the g-factor of the $4^-$ state of the ground state rotational band ($K=0$) of deformed even-even nuclei is same as that of the $2^+$ state of the band. Not many direct measurements are available for the magnetic moments of the second excited states of the deformed nuclei. We have measured the magnetic moment of the $4^-$ state of $^{160}$ Dy using the integral reversed field method of perturbed angular correlation technique. The $297-(682)-397$ keV cascade having the $682$ keV as the unobserved transition has been chosen for the purpose.

The hyperfine magnetic interaction has been brought about by using the $\gamma$ paramagnetic activity of terbium in the form of terbium chloride in $dil. BCl$, and an externally applied magnetic field of $16.5$ kG.

II. THEOREM

The theory of the unperturbed angular correlation of a triple cascade $\gamma_1(\gamma_2, \gamma_3)$ with the unobserved $\gamma_2$ transition is well established, and the expression has been found by Frauenfelder and Steffen, as

$$W(k, \vec{k}_1) = \sum_{k'kk} a_{kk} P_k (\cos \theta_k) \quad \ldots \ldots (1)$$

with $a_{kk} = a_k ^{(1)} a_k ^{(2)} a_k ^{(3)} a_k ^{(4)} \quad \ldots \ldots (2)$$

Following the treatment of Frauenfelder and Steffen, of the perturbation of an ordinary $\gamma - \gamma_2$ cascade, we have obtained for the $\gamma_1 - \gamma_2 - \gamma_3$ cascade,

$$W(k, \vec{k}_1, \vec{k}_2) = \sum_{k,k',k''} a_{k2} (2k_2 + 1) a_3 (2k_3 + 1) \left( \frac{\Delta I}{\Delta I} \right) \left( \frac{\Delta J}{\Delta J} \right) \left( \frac{\Delta M}{\Delta M} \right) \frac{\Delta J_3}{\Delta J_3}$$

$$\times \frac{\Delta M_3}{\Delta M_3} \gamma_{k_3, k_2} \gamma_{k_2, k_1} \gamma_{k_3, k_3} \quad \ldots \ldots \ldots (3)$$

where the perturbation factor has been defined as
The last factor of reduced matrix elements in (4) along with the phase factor $(-)^k$ is the $U_k$ coefficient of (2). For the case when the perturbation is caused by the interaction of the nuclear magnetic moment with an external magnetic field $B$ (applied along the $z$-axis, with the radiation detectors in the $x$-$y$ plane), the eq. (3) reduces to

$$W \left( \frac{2\hbar c}{\hbar}, t_a, t_b, \vec{B} \right) = \sum_{N} N \exp \left[ i \left( \sum_{k} U_k \frac{\hbar c}{\hbar} \right) \right],$$

with the $U_k$ coefficients given by eq. (251) of reference 1, but in which $H_{\alpha k}$ has been replaced by $H_{\alpha k}$ of (2) above. The instants $t_a$ and $t_b$ refer to those of the decays of upper and lower levels of the unobserved transition.

The total time-integrated correlation is calculated as:

$$I(t_a, t_b) = \frac{1}{N} \sum_{N} \exp \left[ i N \left( \sum_{k} U_k \frac{\hbar c}{\hbar} \right) \right] \int_{t_a}^{t_b} \cdots \int_{t_b}^{t_b} \cdots \int_{t_a}^{t_a} \cdots$$

which can be written as:

$$1 + \sum_{N} \frac{N^{\alpha k} \tau_{\alpha k}^{\text{obs}}}{N \omega_{\alpha k}} \cos \left( N \frac{\hbar c}{\hbar} \right),$$

where the precession angle $\theta_{\alpha k}$ is given by:

$$\tan \theta_{\alpha k} = \frac{N^{\alpha k} \tau_{\alpha k}^{\text{obs}}}{N \omega_{\alpha k}} \cos \left( N \frac{\hbar c}{\hbar} \right),$$

and by $-\frac{\Delta A_{\alpha k}}{4 \pi} \omega_{\alpha k}$ (for the case when $k_{\text{max}} = 2$, i.e., $A_{\alpha k}$ is zero).

The expression for the 'B' parameter defined as $B = \frac{2}{C_{\text{max}}} \frac{C_{\text{max}}}{C_{\text{max}}}$ also gets modified as:

$$B = \frac{2}{C_{\text{max}}} \frac{C_{\text{max}}}{C_{\text{max}}} \cos \left( N \frac{\hbar c}{\hbar} \right).$$

This expression will be used in the next section to calculate the precession angle.

III. EXPERIMENTAL RESULTS

Fig.1 shows the partial level scheme of $^{160}$.
Fig. 1. Partial Level Scheme of \(^{160}\text{Dy}\)
(taken from reference). The \((1,3)\) unperturbed angular correlation of the \(299-(6d^2)-197\) keV cascade of \(^{160}\text{Dy}\) was done on a conventional two channel set up using NaI(Tl) detectors. The gamma energy gate of 197-keV also included a contribution from 216-keV but this gamma ray was not in coincidence with 299-keV. The angular correlation fitted to the expression
\[
\mathcal{W}(\theta) = 1 + A_{22} P_2(\cos \theta) + A_{44} P_4(\cos \theta)
\]
gave
\[
A_{22} = 0.120 \pm 0.015 \text{ and } A_{44} = 0.06.\]
These coefficients are not corrected for the geometry and are comparable to those obtained by Krane and Steffen.  
We assume that the time dependent perturbations are absent in both the 299-6d2-keV and 6d2-197keV cascades, because the intermediate levels of 966-keV and 216-keV involved are considerably short lived \(^3\).  

The precession measurements were done using the same geometry and same energy gates as those used for angular correlation measurements.  
An external magnetic field of 16.5 kG normal to the planes of the two detectors was applied to the liquid source of terbium (chloride in dii. H2O). The relative change \(R(\theta, \pm \theta)\) of the coincidence counts upon reversal of the field was measured at \(\theta = 45^\circ\) and \(135^\circ\). The results were
\[
R(45) = -0.0083 \pm 0.0014, \text{ and } R(135) = +0.0075 \pm 0.0013 \text{ (the errors are statistical only).}
\]
A mean value of the two gives \(R = 0.0078 \pm 0.0010.\)  
From the eq.(8) of section II, one obtains
\[
\omega_p T_p + \omega_m T_m = 0.024 \pm 0.003 \text{ rad}
\]
Applying the paramagnetic correction \(\beta (2g^2) = 6.3\) as calculated by Hunter and Lindgren, the effective magnetic field being experienced by dysprosium nuclei becomes \(H_{\text{eff}} = 10.04\). With this effective field and the known g-factor and lifetime values of the 966-keV state from Simon et al.\(^5\), it can be calculated that the rotation \(\omega_p \tau_p\) of this state is \(-1/50\), which is negligibly small as compared to the detectable error of present measurement.
Neglecting $\omega_1$, therefore, one obtains $\omega_2 = 0.024 + 0.003$ rad. Using the $\frac{1}{2}(2\alpha_s - \alpha_s')$ (see (2a) of the previously existing measurements, and the relation $g = \frac{\omega_2}{\omega_1}$, we obtain $g(2\alpha_s - \alpha_s') = 0.34 \pm 0.05$.

The hydrodynamic model gives a value of $g = 0.7$ for the $K=0$ band of $^{160}$Dy. Griner's calculations give a lower value of $g = 0.35$ for this band. Our present value of the $g$-factor is nearer to Griner's value and is also comparable with the $g$-factor of the $2^+$ level at 87-keV obtained by Ofar et al. 7)

REFERENCES

4) C. G. K. Linde and P. A. Lindhagen: Perturbed Angular Correlations ed. E. Karlsson et al. (North-Holland, 1964) Chapter IV.
7) S. Ofar, M. Bakavy, and E. Segal, Nucl. Phys. 69 (1965), 173.

DISCUSSION

B. F. Singh: Have you taken care of the compton distribution of the higher gamma rays in this cascade?

A. K. Dhar: Yes. We measured the angular correlation between 197-keV gamma and coincident compton background. It was observed to be isotropic at 4 angles 90°, 120°, 150°, 180°. So we need not worry about it in rotation measurements.
FIG. 4.10 PHOTOGRAPH OF THE ACTUAL SET UP.