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ABSTRACT

The half-life of the 74.8 keV level in Rh¹⁰⁰ has been measured by delayed coincidence techniques. The result is $T_{1/2} = 235 \pm 3$ nsec. Using the time-dependence of the 84-74.8 keV angular correlation in an external magnetic field, the g-factor of the 74.8 keV level was found to be $g = +2.13 \pm 0.03$.

I. INTRODUCTION

The decay of 4 day Pd^{100} has recently been investigated in detail by Evans and Naumann.¹ The authors studied both the γ -ray and the conversion electron spectra and established the decay scheme shown in Fig. 1. The spin sequence and the multipolarities of the 84-74.8 keV cascade as well as the long half-life of the 74.8 keV level² make this cascade very attractive for perturbed angular correlation measurements. A rough check of the anisotropy of this cascade gave a value of $A = + (29.7 \pm 1.8)\%$ even larger than the value $(18 \pm 3)\%$ given by Evans and Naumann. This large anisotropy makes it easy to detect the Larmor precession of the spin of the intermediate level in an external magnetic field and thus to determine the magnetic moment of the 74.8 keV level. The knowledge of this magnetic moment would be of interest because it elucidates the structure of the 74.8 keV level, which has been assigned¹ on the basis of the j-j coupling rules of Brennan and Bernstein³ for odd-odd nuclei. Another interesting aspect is the application to solid state problems such as magnetic hyperfine interactions. Rh is a transition element with an unfilled 4d shell and much interest has focused recently on hyperfine interactions involving transition elements in intermetallic compounds and transition element impurities in magnetic lattices.⁴

II. MEASUREMENTS AND RESULTS

A. Source Preparation and γ -Spectrum

The $4d$ Pd^{100} activity was produced by a $(p, 4n)$ -reaction on natural Rh^{103} . The irradiation was performed at the 88-in. cyclotron of the Lawrence Radiation Laboratory using a proton beam of about 20 μA -h and an energy of 45 MeV. For spectrum and half-life measurements the target material was used without further preparation. The g -factor measurements have been carried out both with a piece of the rhodium target and also with a source of rhodium in very dilute solution in copper. To prepare the latter source the Pd activity was chemically separated from the Rh target using a procedure described by Evans and Naumann.¹ The palladium was then electroplated carrier-free onto a copper foil. The foil carrying the activity was molted in an argon atmosphere at about 1200°C. The result was a shiny copper ball with a diameter of about 0.5 mm which was used for the angular correlation measurements.

The measurements were done exclusively with Ge(Li) detectors of 1 2 cm² and a 3 mm deep drifted layer. Low-noise preamplifiers with an EC 1000 input stage as described by Goulding⁵ were used in connection with the detectors. A typical γ -spectrum obtained with our setup is shown in Fig. 2. For calibration purpose the well known γ -rays of Co^{57} are indicated. The spectrum is in good agreement with the result of Evans and Naumann and confirms the decay scheme shown in Fig. 1. In addition we see clearly the two low-energy transitions at 32.7 and 42.1 keV.

For angular correlation measurements with the 84.0-74.8 keV cascade a Ge(Li) detector setup is ideal as there is no difficulty in making a clear energy separation between these two γ -rays, whereas it is impossible to resolve the two peaks with NaI(Tl) detectors.

B. Half-Life of the 74.8 keV Level

For measuring coincidences of the 84.0-74.8 keV cascade as a function of time we used a time-to-height converter described by Wieber⁶ which was modified to give a linear time range of 1 μ sec. To trigger the converter a "fast" output pulse was taken from the preamplifiers, amplified by a factor of 400 in a transistorized wide-band amplifier (risetime 10 nsec) and put into a 100 Mc tunnel diode discriminator. The output of the discriminator served directly as input signal for the time-to-height converter. The energy selection was done in the conventional way by gating the multichannel analyser with the output pulses of a slow coincidence unit with a time resolution of 2 μ sec.

For the time calibration the delay trigger of a type 555 Tektronix Dual Beam Oscilloscope was used, delaying the "stop" pulses with respect to the "start" pulses by a known amount. To obtain an absolute time scale the delay trigger was in turn calibrated with a 10 Mc crystal-stabilized frequency. The overall accuracy of the calibration is better than 1%. For the half-life measurements the Ge(Li) detectors were placed at an angle of 180° and moved together as close as possible. However, there was still a distance of about 1 cm between the source and each detector surface. In view of the large anisotropy we can therefore not rule out completely the influence of a small perturbation effect on the half-life.

The result of a typical half-life measurement is shown in Fig. 3. Altogether we performed three independent runs, the results of which are summarized in Table I. The final value for the half-life

$$T_{1/2} = 235 \pm 3 \text{ nsec}$$

is not in agreement with the result of Evans and Naumann.² These authors, however, performed their measurements with a conventional fast-slow coincidence circuit only, introducing artificial delays. The use of a time-to-height converter is undoubtedly the more reliable way to measure half-lives.

Evans and Naumann concluded from their result a hindrance factor of 5×10^5 with respect to the Weisskopf estimate 5.1×10^{-13} sec for an E1 transition of 75 keV. The new half-life value gives a hindrance factor of 9.3×10^5 , using $\alpha = 0.3$ and the total transition intensities reported in Ref. 1.

C. Uncorrected g-Factor of the 74.8 keV Level

The long half-life of the 74.8 keV level and the large anisotropy of the 84.0-74.8 keV cascade make it an ideal case for time-differential angular correlation measurements. Thus, the g-factor was measured by observing the Larmor precession of the angular correlation pattern in an external magnetic field.⁷

The electronic setup for this kind of measurements is identical with the one described for the half-life measurements. The geometry chosen for the experiment was that the γ_2 detector was at an angle of 225° with respect to the γ_1 detector, counted clockwise from γ_1 toward γ_2 . A measurement then consisted of two sets of data, each for opposite field directions. From the coincidence rate in channel number i for a magnetic field pointing upward ($C_{i\uparrow}$) and downward ($C_{i\downarrow}$) the normalized ratio

$$R_i = 2 \frac{C_{i\downarrow} - C_{i\uparrow}}{C_{i\downarrow} + C_{i\uparrow}}$$

was calculated. If the time resolution of the converter is negligible

compared with the time required for half a cycle the ratio can be expressed as a function of the Larmor precession frequency $\omega_L = -g \cdot H \mu_N / \hbar$:

$$R(t) = \frac{(12A_2 + 5A_4) \sin 2 \omega_L t}{8 + 2A_2 + 1/8 A_4 (9 - 35 \cos 4 \omega_L t)},$$

where A_2 and A_4 are the usual angular correlation coefficients. According to the spin sequence given by Evans and Naumann we expect in this particular case $A_4 = 0$. For this reason the data were fitted to the function

$$R_i = a \cos 2(\omega_L t_i - \phi) + c.$$

The anisotropy A and the amplitude a of the cosine wave are connected by the relation

$$A = a \frac{1 + 1/4 A_2}{1 - 1/2 A_2}.$$

In an earlier report on g -factor measurements in Ru^{99} the difficulty of a paramagnetic correction in liquids was discussed.⁸ The Ru occurred only in paramagnetic complexes and a correction was impossible as nothing is known about the abundance of the different oxidation states after the EC decay has disturbed the electronic shells. The situation in the rhodium case is expected to be very similar: rhodium tends to form complex compounds and the EC decay of the Pd surely leaves the rhodium in various oxidation states. Following the conclusion resulting from the ruthenium work⁸ we performed measurements only with cubic metallic sources. In the present paper results obtained with copper and rhodium sources will be reported.

In Fig. 4 a typical result obtained with a copper source is shown. In the upper part of the figure the raw data for both magnetic field directions are displayed and in the lower part the corresponding ratio R_1 together with the best fit. In Fig. 5 the result measured with a rhodium source (target material) is shown. It is obvious from these figures that in both cases there is not the slightest time-dependent attenuation present. This clearly indicates that the nuclear-lattice relaxation is still at least an order of magnitude longer compared with the measured range of 1 μ sec. Also the quality of the fit in all cases rules out the presence of a quadrupole perturbation arising from a distortion of the cubic lattice.

A summary of all results obtained with the copper and the rhodium sources is given in Table II.

D. The Knight Shift Correction

The advantages of metallic sources for perturbed angular correlation measurements have been discussed earlier.⁸ One such advantage is that the external magnetic field is modified in metals essentially only by the Knight shift, $K = \Delta H/H$, which is usually of the order of a 1% correction. Often this correction is known from NMR measurements or can be estimated by analogy with known shifts.

In this work we used a copper lattice to minimize the possibility of a large Knight shift. The high susceptibility of metallic rhodium left open the possibility, we felt, of a Knight shift of up to a few percent because of the open 4d band. While this work was in progress Seitchik et al.⁹ reported NMR measurements on Rh^{103} in several environments, and gave an estimate of $R = + 0.43\%$ for Rh nuclei in Rh metal at room

temperature. We use this value of K as a correction for our Rh in Rh results, obtaining a final g factor for the 74.8 keV state of Rh¹⁰⁰

$$g = + 2.13 \pm 0.03 .$$

The final error includes uncertainties of 1% for the time-calibration, 1% for the magnetic field, and the statistical error quoted in Table II. The Rh in Cu data cannot be used to yield a g factor because the appropriate Knight shift correction is not independently known. We may, however, derive a value for this shift from the data in Table II:

$$K (\text{Rh in Cu}) = + 1.0 \pm 0.4\% .$$

Systematic errors have largely cancelled here. This shift is small and positive as expected for polarization of the open s conduction band and reinforces the above interpretation.

III. DISCUSSION

Low-lying intrinsic states of odd-odd nuclei are usually considered to be derived by coupling neutron (ν) and proton (π) states. Often these states are found in neighboring odd-A nuclei. Evans and Naumann have suggested (ν, π) configurations for the first four states of Rh¹⁰⁰. For the 74.8 keV state they proposed the configurations I $[\pi(g_{9/2}^5)_{9/2} \nu(d_{5/2}^{5-n} s_{1/2}^n)_{5/2}]_{2+}$ or II $[\pi(g_{9/2}^5)_{7/2} \nu(d_{5/2}^{5-n} s_{1/2}^n)_{3/2}]_{2+}$. If we assume that the ν configurations are the same as those of ground state ($5/2 +$) and 90-keV first excited state ($3/2 +$) in Ru⁹⁹, we may take the g factors as those measured for these two levels, -0.25 and -0.19 respectively.⁸ For the proton configuration we take $g = +1.25$, interpolated from the values +1.37, +1.26,

and +1.23 for the $g_{9/2}$ proton states in Nb⁹³, Tc⁹⁹, and In^{109,111,113,115}, respectively.¹⁰ For configurations I and II above we calculate g factors of +2.50 and +1.97, respectively. The large value of +2.13 for the experimental g factor is quite distinctive and definitely establishes a major contribution from the $g_{9/2}$ proton shell. The experimental value is considerably closer to the g factor of II than that of I; therefore favor II. There is evidence¹¹ for the $\pi(g_{9/2}^7)_{7/2}$ configuration in the 6+ isomer of Ag^{110m}. The approximation of using the first excited state of Ru⁹⁹ to estimate $g(\nu)$ may not be valid; if not, the value of $g(\nu)$ is probably more negative. From the systematic behavior of 9 $d_{5/2}$ neutron states in this region¹⁰ we may estimate $g_{5/2+} \cong -0.30$. If we take this as the g factor of the ν configuration, the g factor for the state in question is raised to +2.03, only 5% below the experimental value.

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FOOTNOTES AND REFERENCES

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Table I. Summary of the results of three half-life measurements.
A time calibration was done for each individual run.

Run No.	Source material	$T_{1/2}$ (nsec)	$\Delta T_{1/2}$ statistical error
1	Rh in Rh (annealed)	236.6	2.5
2	Rh in Ag	230.7	2.5
3	Rh in Rh (target)	235.5	1.7
	Weighted average:	234.6	1.6

Table II. Summary of g-factor measurements with copper and rhodium sources. In all cases the external magnetic field was 2.22 ± 0.02 Kgauss. The amplitudes are given to emphasize the consistency of the different runs but include no solid angle correction. A separate time calibration has been done for each individual run.

Run No	Source	Uncorrected g-factor	Statistical error Δg	Amplitude a(%)
1	Rh in Cu	2.1598	0.0055	26.1 ± 0.5
2	Rh in Cu	2.1549	0.0087	25.6 ± 0.7
3	Rh in Cu	2.1359	0.0079	25.3 ± 0.7
	Weighted average:	2.1526	0.0071	
1	Rh in Rh	2.1360	0.0092	24.1 ± 0.7
2	Rh in Rh	2.1434	0.0074	23.8 ± 0.6
	Weighted average:	2.1405	0.0058	

FIGURE CAPTIONS

Fig. 1. Decay scheme of Pd^{100} as given by Evans and Naumann, ref. 1.

Fig. 2. Typical γ -spectrum of Pd^{100} obtained with a Ge(Li) detector of 3 mm depletion depth and an active surface of $1 \times 2 \text{ cm}^2$. The Co^{57} calibration lines of 122.0 keV and 136.4 keV are shown.

Fig. 3. Half-life of the 74.8 keV level. The measurement shown is run no. 3 in Table I. The quoted error represents only the statistical uncertainty of this run.

Fig. 4. Time-differential g-factor measurement with a source of Rh^{100} in copper in an external field of ± 2.22 Kgauss. In the upper part of the figure the raw data of run no. 1 in Table II are shown without any background correction. In the lower part the corresponding ratios R_i are displayed. The full line represents the weighted least-squares fit to the data.

Fig. 5. Result of the g-factor measurement (run 2 of Table II) with a source of Rh^{100} in Rh metal in an external magnetic field of ± 2.22 Kgauss. The full line represents the weighted least-squares fit to the ratios R_i .

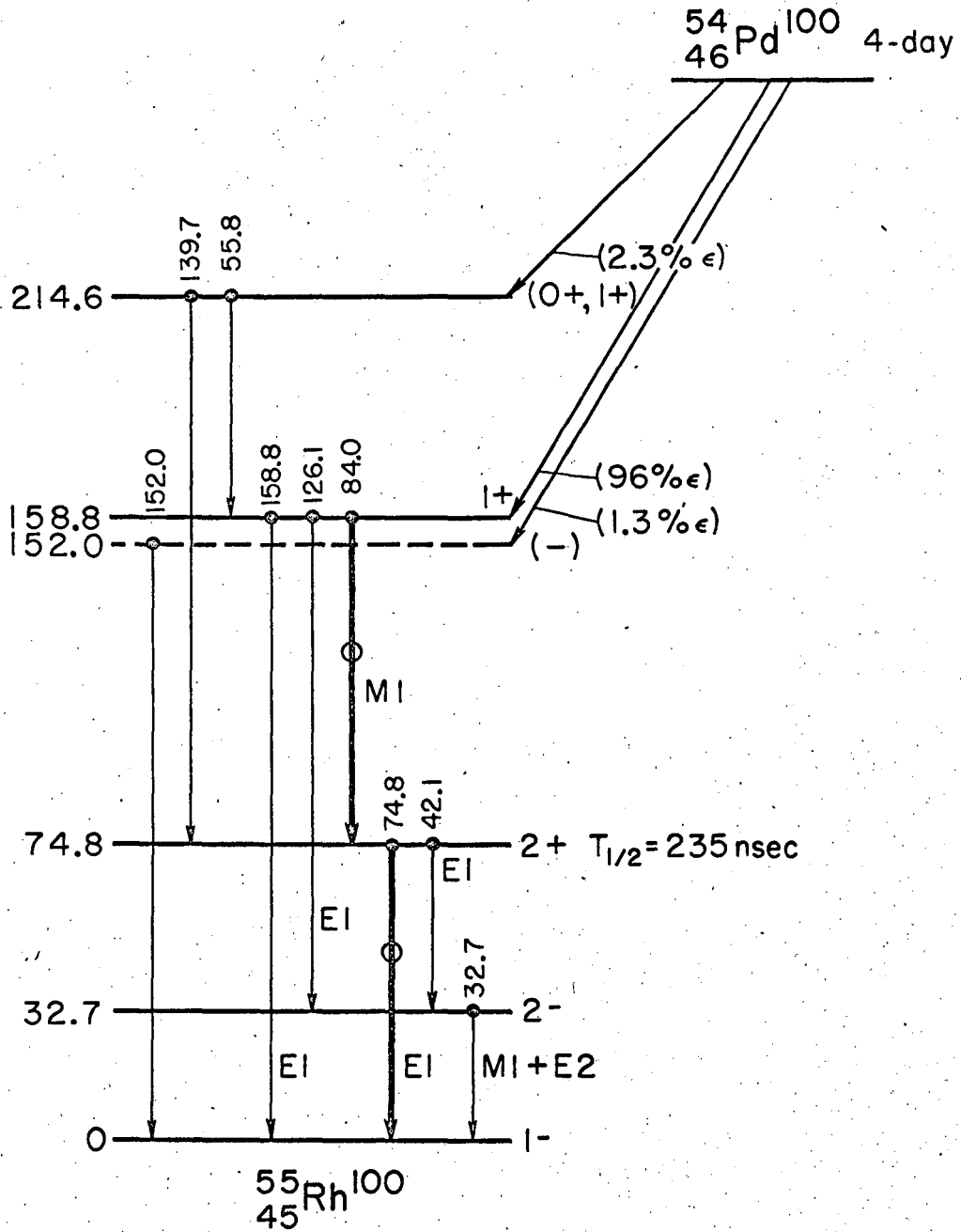
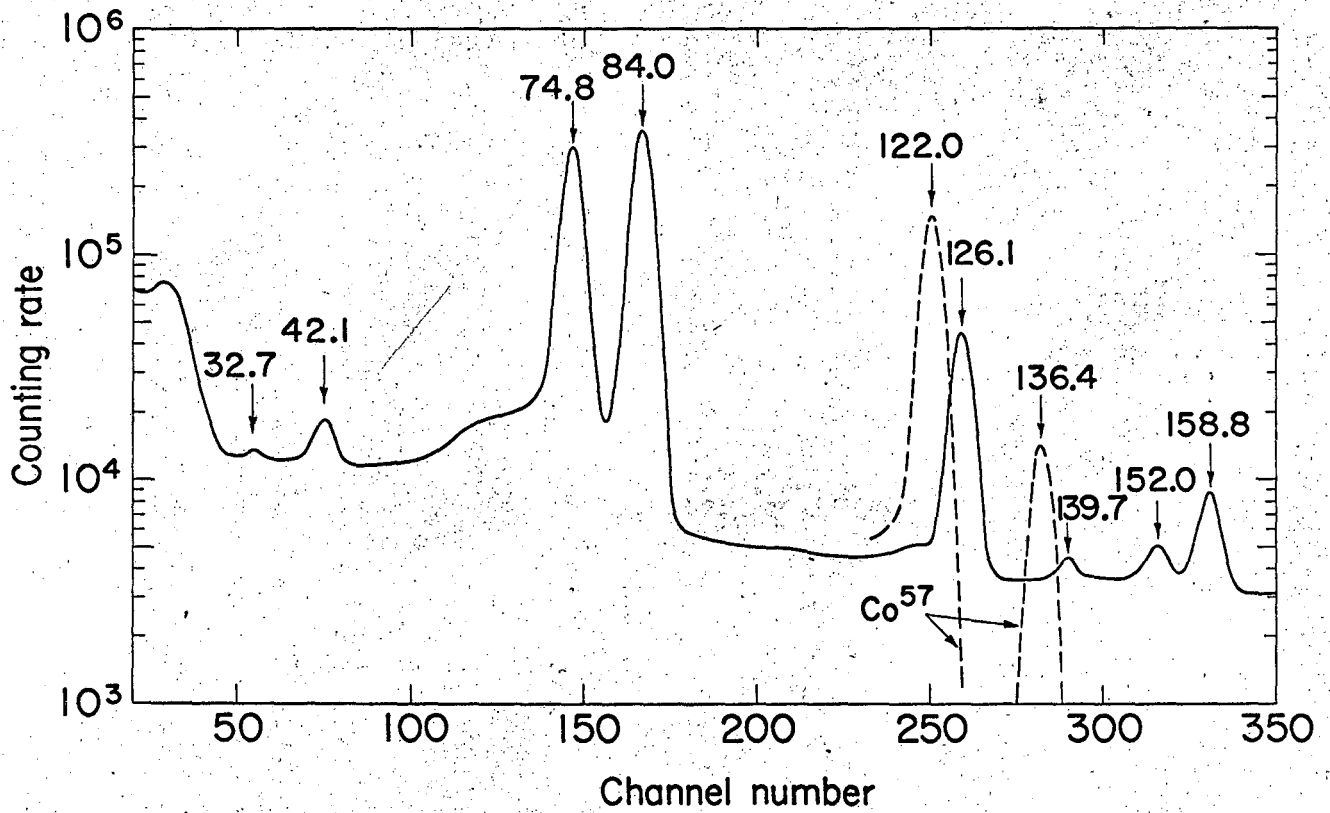


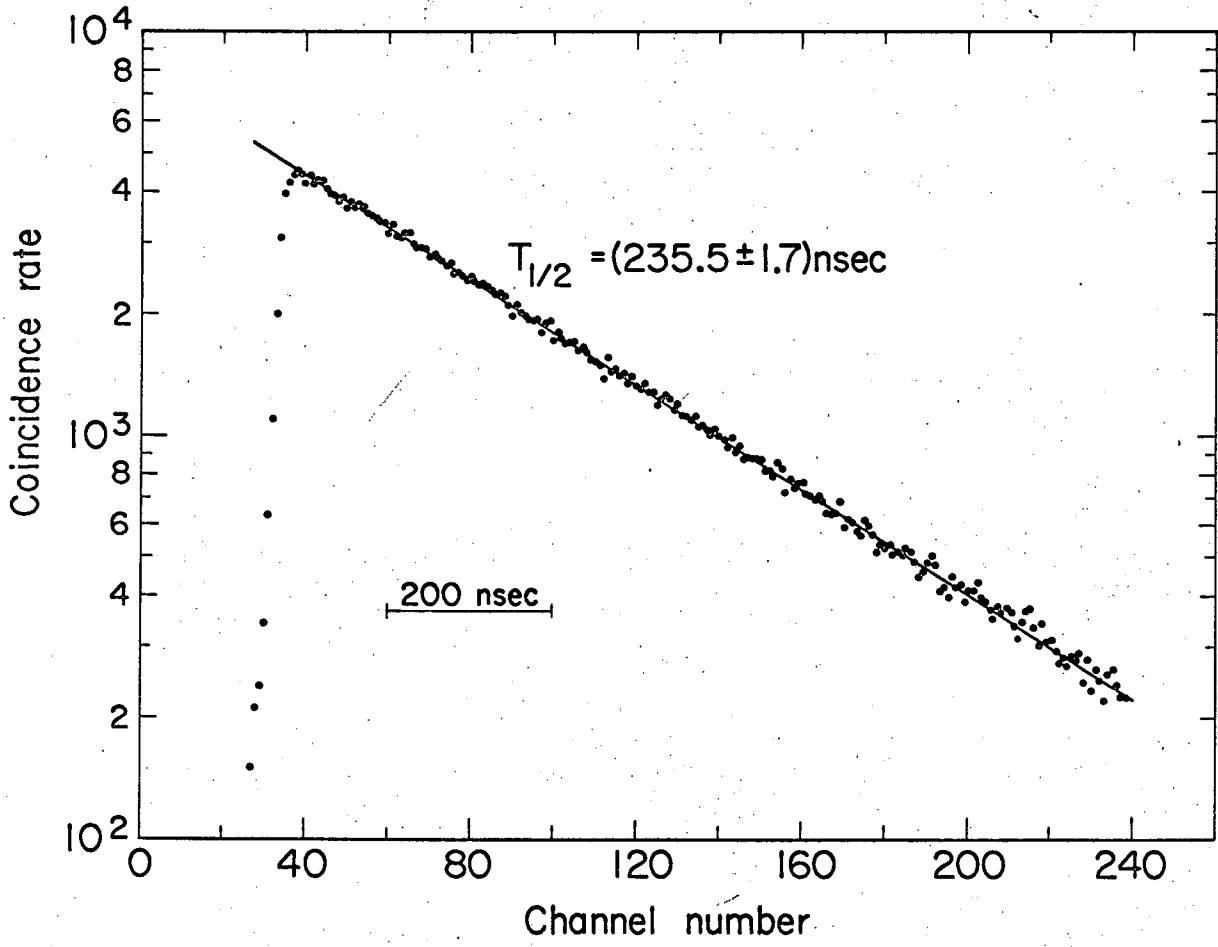
Fig. 1

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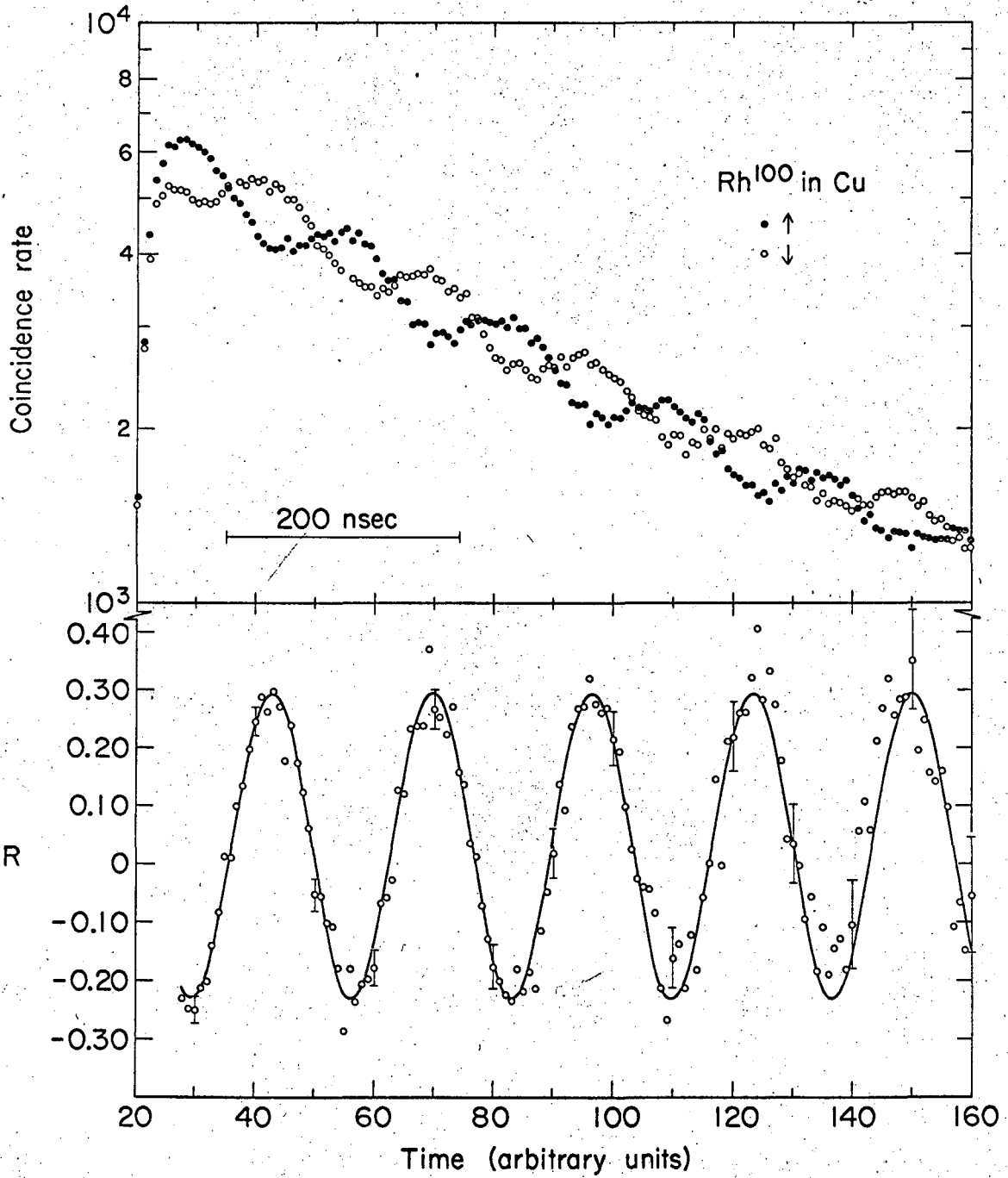
MUB-5970

Fig. 2



MUB-5969

Fig. 3



MUB-5971

Fig. 4

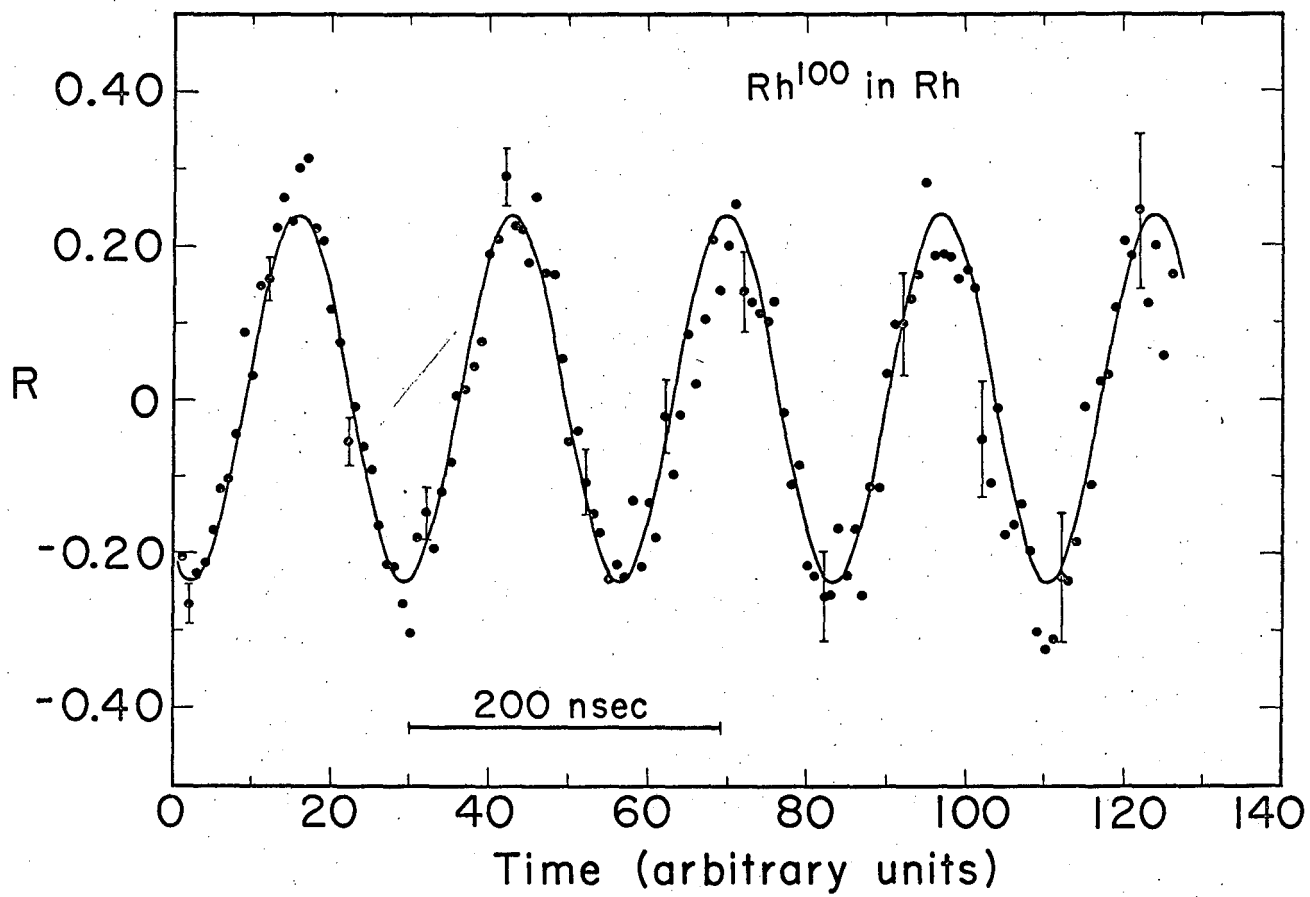


Fig. 5

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