Heavy ion excitation and spin-precession of a new isomer of ^{72}As in Co and Ni

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A new isomeric level at 561 keV [$T_{1/2} = 87(2)$ nsec] in ^{72}As has been excited by the reaction ^{59}Co(^{16}O,2pn)^{72}As using pulsed beams of ^{16}O. The spin-precession of this level has been observed in cobalt, and also, after recoil implantation, in nickel. The g factor is measured to be $g = +0.116(2)$, which yields +274(7) kG for B_{hf}(As$\underline{Co}$).

[NUCLEAR REACTIONS Pulsed beam: ^{59}Co(^{16}O, 2pn); observed isomeric level; measured $T_{1/2}$, spin-precession in Co, Ni; deduced g, B_{hf}.]

In recent years a large number of nuclear isomeric states have been excited by nuclear reactions with pulsed beams of light projectiles (p, d, α) and their spin-precession has been extensively applied to the study of hyperfine interactions in the target material. A powerful extension of this technique is the application of heavy-ion (HI) reactions. Due to the large angular momentum transfer involved, these reactions selectively populate high-spin states providing an opportunity to observe many new and well-aligned isomeric levels. In addition, the high recoil energy available for the residual isomer can be used for recoil implantation into any desired host. Thus, HI reactions have the important advantage that one can independently choose the nuclear and extranuclear aspects of a system to be studied without need for multilayer sandwich targets. In this paper we report the observation of a new isomer of ^{72}As populated by the reaction ^{59}Co(^{16}O, 2pn) ^{72}As, its magnetic spin-precession in the ferromagnetic Co target, and after recoil implantation, its spin-precession in nickel.

The experiments were performed with a pulsed ^{16}O beam of energy 53 to 56 MeV from the Rutgers-Bell tandem accelerator. The pulse width of the beam burst was ~2 nsec and the repetition period, 1 μsec. γ rays were detected by a planar Ge(Li) detector, 7 mm × 10 cm^2 with an energy resolution ~1 keV at 122 keV and an overall time resolution of ~7 nsec for 200 keV γ rays. The time structure of the radiation was observed by a conventional time-to-amplitude converter (TAC) started by a suitably shaped pulse from the Ge(Li) detector and stopped by a pulse picked up from the main oscillator of the pulsing system. The energy spectrum at any desired time interval after the beam burst as well as the time spectrum of any desired γ ray could be obtained simultaneously by appropriate electronic gating.

Figure 1 shows the spectrum of delayed ($t > 50$ nsec) γ rays from a 8 mg/cm^2-thick target of metallic cobalt. The γ rays at 53, 95.5, 199, and 309 keV were all observed to decay exponentially with an identical half-life $T_{1/2} = 87(2)$ nsec, while those at 167 and 213 keV displayed time spectra typical of the decay of an isomeric state populated by another isomer at higher energy and with a comparable half-life. A level at 213 keV in ^{72}As has previously been observed[1] to be isomeric with $T_{1/2} = 80(2)$ nsec, decaying by the emission of two γ rays at 167 and 213 keV. The lines at 95 and 309 keV have been observed before[2] in the reaction ^{72}Ge(p,n) ^{72}As, and very recently the γ rays at 53 and 199 keV have been observed[3] in the ^{70}Ge(α,np) ^{72}As reaction. None of these studies, however, reported the delayed emission of the γ rays seen in the present work. All the present data are consistent with the population in ^{59}Co (^{16}O, 2pn)^{72}As, of an isomeric state, presumably of high spin and with $T_{1/2} = 87(2)$ nsec emitting the 199 keV γ ray and followed by γ rays at 53, 95.5, 309, 167, and 213 keV, populating in the process also the isomeric state at 213 keV in ^{72}As. These premises were confirmed in detail by recording γ-ray spectra in coincidence with the above γ rays as well as by delayed coincidence measurements between individual γ rays using an additional NaI(Tl) detector. The results are summarized in the decay scheme in Fig. 1 and are consistent with that proposed in Ref. 3. The present work thus reveals that a new isomer in ^{72}As

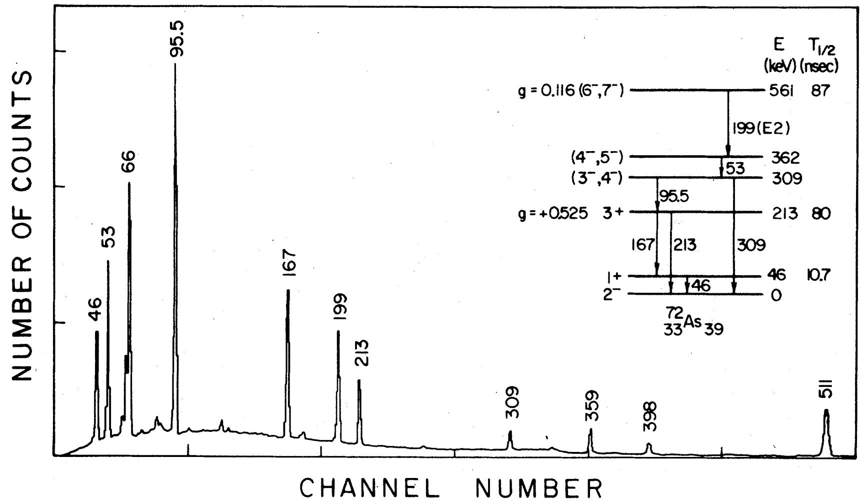

FIG. 1. Delayed γ rays ($t > 50$ nsec) from bombardment of the Co foil with the 53 MeV ^{16}O beam. The energies of the prominent γ rays are indicated. The inset shows the proposed decay scheme of the new isomeric state at 561 keV.

at 561 keV is strongly excited in the reaction ^{59}Co(^{16}O, 2pn) ^{72}As. The normalized yield of the γ rays and their intensity ratios as a function of projectile energy between 43 and 56 MeV, as well as preliminary analysis of the growth-decay time spectra of the 167 and 213 keV γ rays, show that the delayed γ spectrum of ^{72}As in this reaction is from the depopulation of the 561 keV level. The γ rays at 66 and 361 keV were identified as those of ^{73}As from the radioactivity of ^{73}Se. The γ ray at 398 keV was observed to have a lifetime greater than 1 μsec and was identified as that from the 2.8 μsec isomer in ^{69}Ge.

Since Co is ferromagnetic, one expects a hyperfine interaction of the magnetic moment of the 561 keV isomeric state. To observe this, the time spectra of the 53, 95.5, 199, and 309 keV γ rays were recorded with the Ge(Li) detector at 0° to the beam and with no external magnetic field on the target. The exponential decay of these γ rays is then modulated by a perturbation factor of the form[4] appropriate to random orientation of the magnetic field. Well-defined modulations were observed for the 199 keV γ ray (see Fig. 2). After subtraction of background and normalization for exponential decay, excellent fits of these mod-

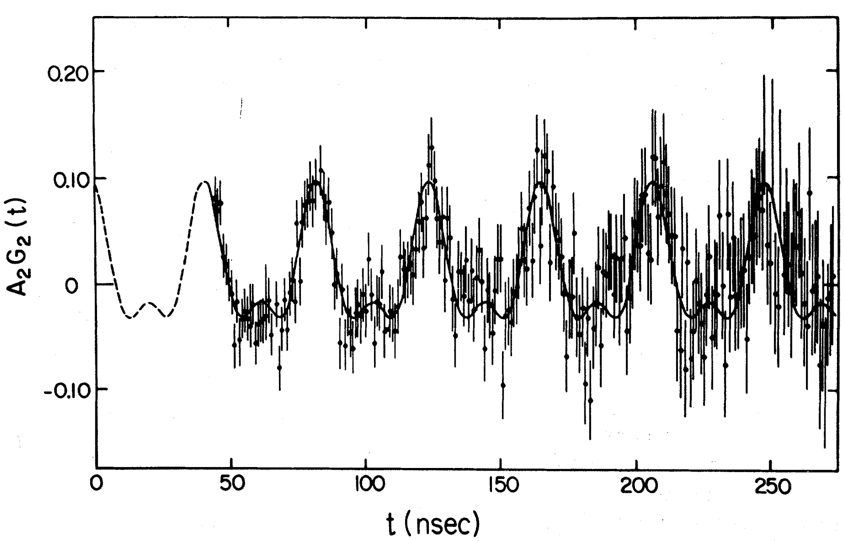

FIG. 2. Spin-precession of the 199 keV γ rays of ^{72}As in a randomly oriented internal magnetic field at As nuclei in Co observed with the detector at 0°.

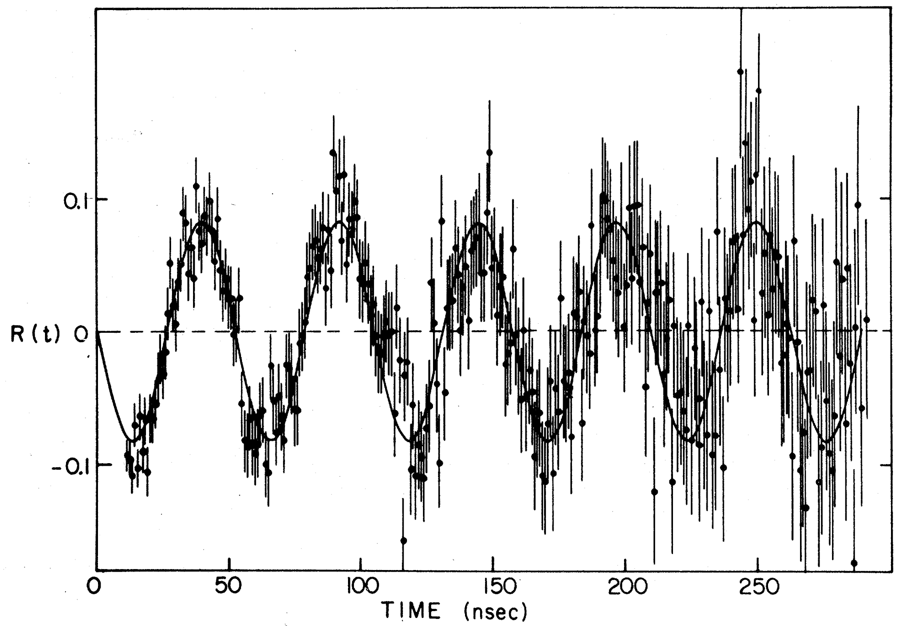

FIG. 3. Spin-precession of the 199 keV γ rays of ^{72}As after recoil implantation into polarized nickel foil. With the detector at 45° to the beam $R(t)=[N(\uparrow)-N(\downarrow)]/[N(\uparrow)+N(\downarrow)]$, where $N(\uparrow)$ and $N(\downarrow)$ refer to the number of counts observed in the two magnetic field directions after subtraction of background.

ulation curves could be obtained with a function of the form

$$F=a_0+a_1\cos\omega_L t+a_2\cos 2\omega_L t \qquad (1)$$

with the following results: (i) The anisotropy coefficients which determine the coefficients a_i of Eq. (1) are $A_{22\mathrm{eff}}\simeq +0.13$, $A_{44}\approx 0$; (ii) The Larmor frequency ω_L (As$\underline{Co}$) = 152.0(5) MHz. No clear modulations were observed for the other three γ rays, indicating that the A_2 for these transitions are very small, possibly due to multipole mixing or the existence of a short (~ 15 nsec) lifetime for the 309 keV level.[3] The positive A_2 for γ (199 keV) indicates the $E2$ character of this radiation.

A precise measurement of the hyperfine field of As in Ni has recently been published.[5] This can be utilized to make an accurate determination of the g factor of the 561 keV level. Using a 600 μg/cm^2 Co target electroplated onto a 6.6 mg/cm^2 Ni backing, the excited ^{72}As nuclei were recoil implanted into Ni. Although the singles γ ray spectrum became more complex due to ^{16}O reactions on the thicker Ni backing, the 199 keV γ ray could be clearly resolved and the time spectrum was free from any interferences. Larmor modulations were observed with the Ge(Li) at +45° to the beam and with an external polarizing field of 1.5 kG applied perpendicular to the reaction plane. The usual ratio $R(t)$ (see Fig. 3) displays these $2\omega_L$ modulations, yielding ω_L (^{72}As in Ni) = 59.93(21) MHz. Taking into account the polarizing field, and using $B_{\mathrm{hf}}=+106(2)$ kG (Ref. 5) for the hyperfine field on As in Ni at room temperature, the g factor of the 561 keV level was determined to be $g=+0.116(2)$.[6] (A measurement was also made without the external field, as in the case of Co above, which showed a slight decrease in ω_L as expected from the positive hyperfine field of As in Ni.) The g factor thus obtained further yields a precise value for the hyperfine field of As in Co as +274(7) kG, where the sign determination was performed with an external field on the Co target. This value is consistent with the earlier but less precise measurement of the hyperfine field at As in Co by the integral perturbed angular correlation technique.[7]

Internal consistency of the decay scheme derived here indicates a spin of 6$^-$ or 7$^-$ for the 561 keV level. A comparison of the experimental value of its g factor and its sign with single particle or empirical estimates[8] for levels arising from the $(\pi^2 P_{3/2})^{-1}(\nu^1 g_{9/2})^1$ ($I_{\max}=6^-$) or the $(\pi^1 f_{5/2})^1(\nu g_{9/2})^1$ ($I_{\max}=7^-$) configurations indicate that a spin of 6$^-$ from $(\pi^2 P_{3/2})^{-1}(\nu^1 g_{9/2})^1$ could be favored. This spin assignment is also suggested for this level in Ref. 3.

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