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The quasi-particle model has enjoyed considerable success recently in explaining the properties of even nuclei. In particular, Kisslinger and Sorensen have developed theoretical techniques for dealing with single-closed shell (SCS) nuclei in some detail.1) Thus the properties of SCS nuclei are of special interest. A quantity that is often quite sensitive to parameters that enter the theory is the excited-state g-factor. Unfortunately, the lifetimes and g-factors of excited states of even spherical nuclei are usually too small to be measurable by conventional techniques in available external magnetic fields, and to our knowledge no measurements for 4+ states in spherical nuclei have been reported. Hopefully, better experimental techniques and larger (perhaps internal) magnetic fields will soon improve this situation.

An exception to this unfavorable conclusion is the 2.083-MeV 4+ level in Ce^{140}. This nucleus has a closed major neutron shell and a closed $g_{7/2}$ proton subshell in the ground state. It displays the characteristic superconducting energy gap between the ground state and first excited state and, with its isotones, has been studied quantitatively by Kisslinger and Sorensen. The 2.083-MeV level, populated in the decay of La^{140}, has a mean life of 4.97 nsec2), well within the range of the angular correlation method. We have determined its g-factor by using the correlation of the 329 keV--487 keV cascade.

The angular dependence of the coincidence counting rate was studied by using a fast-slow coincidence circuit with a resolving time of 18 nsec. Pulses were routed into a Penco 100-channel analyzer triggered by properly delayed time- and energy-sensitive components. Before corrections were made for the background under the 329-keV peak, the data followed the distribution

$$W(\theta) = 1 - (0.047 \pm 0.003)\, P_2(\cos\theta).$$

Background corrections lower the coefficient of P_2 to -0.10 ± 0.03, in fair agreement with the theoretical value of -0.140 for a 3(D)4(Q)2 cascade (Fig. 1). From the absence of an appreciable P_4 term, a limit of 0.5% can be set on the quadrupole content of the 329-keV transition.

In an external field of 10 425 gauss, normal to the correlation plane, the correlation pattern was attenuated from a zero field anisotropy of -0.070 ± 0.007 to -0.067 ± 0.007 and was rotated through an angle of 24 ± 3 deg. On reversal of the field direction, the pattern rotated 20 ± 3 deg in the opposite direction. A more sensitive experiment involving points of maximum slope yielded rotations of 21.70 ± 1.81 deg and 21.50 ± 1.98 deg for the two field directions. A determination at a field strength of 27 970 gauss gave a shift of 33.00 ±1.85 deg (Fig. 2).

Neglecting paramagnetic and quadrupole perturbations, because both La^{+3} and Ce^{+4} have spherically symmetrical (xenon) electronic configurations, we have for a pure $P_2(\cos\theta)$ distribution$^{3)}$

$$W(\theta, B) = B_2\, [1 + (2\omega\tau)^2]^{-1/2} \cos 2(\theta\ \Delta\theta) \qquad (1)$$

where $\Delta\theta = 1/2 \tan^{-1} 2\omega\tau$ is the angle of rotation of the correlation pattern, and other terms have their usual significance.

For this experiment, the relationship between $\omega\tau$ and $\Delta\theta$ implies that a (time integrated) correlation pattern cannot be rotated by more than $\pi/4$ radians regardless of the strength of the applied magnetic field.

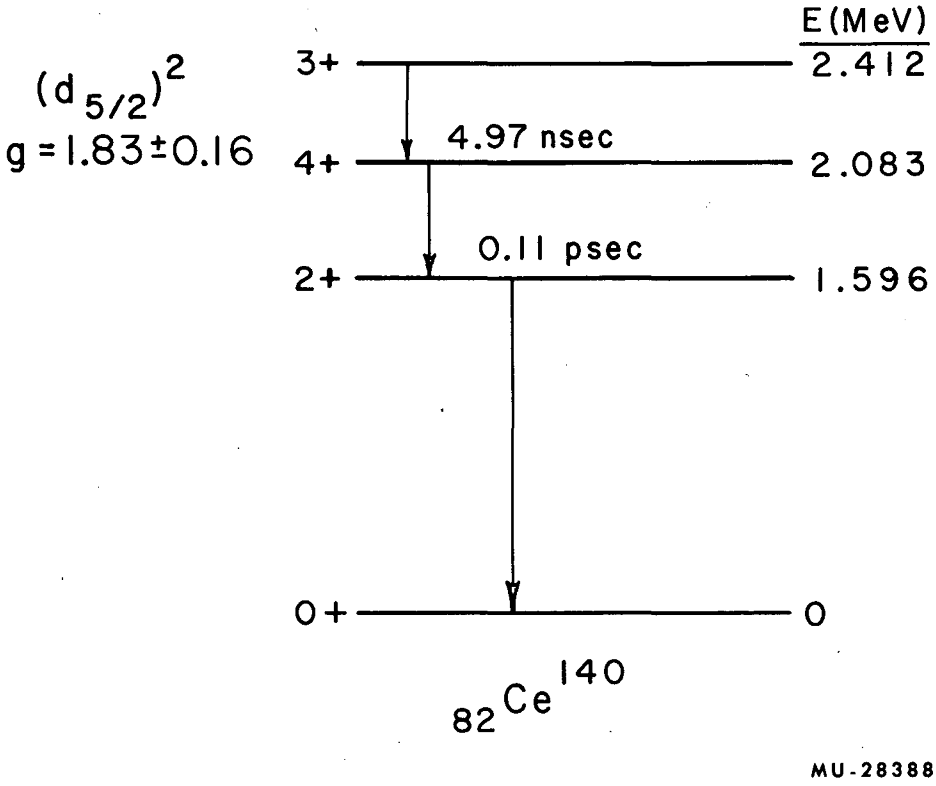

Fig. 1. Energy levels in Ce^{140} relevant to this research, after Currie[2].

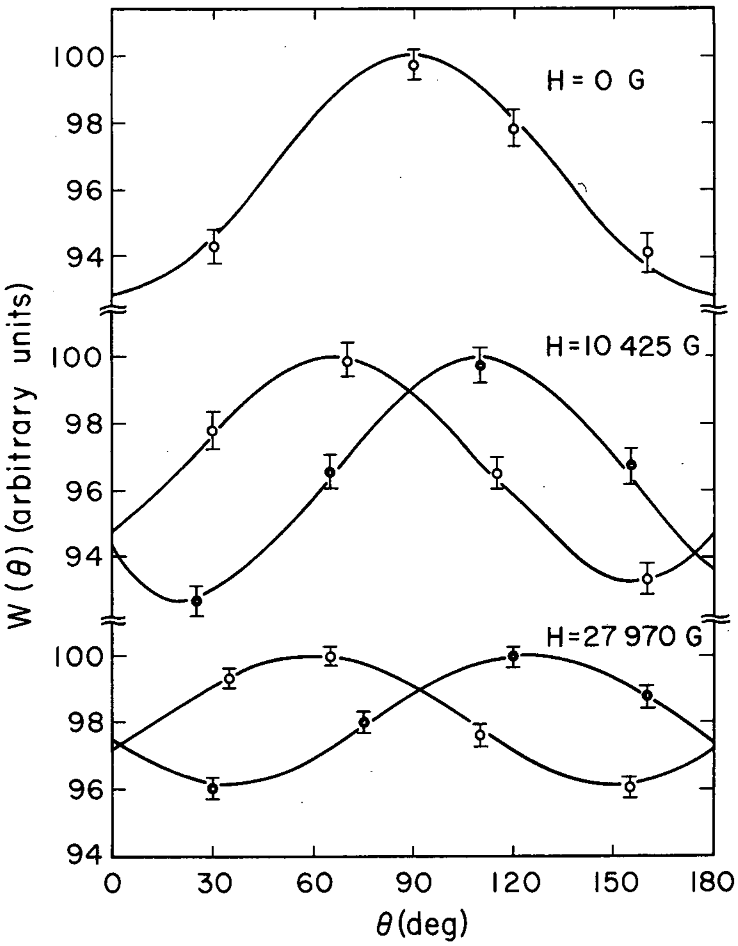

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Fig. 2. Angular correlation of Ce^{140} in zero external field, 10 425-gauss field, and 27 970-gauss field. O field direction up; **O** field direction down.

In fact, it can easily be shown that, for a fixed angular resolution, the minimum fractional error in $\omega\tau$ is achieved at $\Delta\theta = \pi/8$. Thus, although our high-field run gave a smaller fractional error in $\Delta\theta$, it yielded a less accurate g-factor.

The three angles of rotation, when corrected for the finite resolving time of the apparatus and the anisotropy of the background under the peak, lead to three values of the nuclear g-factor. The values are within experimental error of each other and result in an average g-factor of

$$g(2.083) = +\,1.83 \pm 0.16. \qquad (2)$$

The sign is derived from the direction of the rotation relative to the magnetic field.

One might predict a priori that the 2.083 level is essentially a seniority-two state derived from a broken pair in the $g_{7/2}$ proton subshell. This is supported by the quasi-particle model.1) Any state formed entirely from identical nucleons in one subshell must have the same g-factor as does a single nucleon in that subshell regardless of the particular vector coupling scheme involved. Thus, in first approximation this state might be expected to have the $g_{7/2}$ proton g-factor of +0.491. The experimental value of + 1.83 is in marked disagreement with this simple picture.

In the single particle model, the $d_{5/2}$ proton subshell lies near the $g_{7/2}$ subshell in this region. Moreover, Kisslinger and Sorensen have found that the $(g_{7/2})^2$ quasi-particle state should appear at a slightly lower energy than the $(d_{5/2})^2$ configuration in Ce^{140}, but that the order is reversed in Nd^{142}. The g-factor of a $(d_{5/2})^2$ proton state is + 1.92, in very good agreement with this experiment. We conclude therefore that the 2.083-MeV level (the lowest known 4+ level) has $d_{5/2}$ character rather than the expected $g_{7/2}$ character. Perhaps this arises from more favorable overlap in the $[(d_{5/2})^2; 4+]$ state, in which the single particle angular momenta are more nearly parallel.

Configuration mixing would require that the 2.083 MeV state be characterized by the vector

$$|\psi_{2.083}\rangle = (1 - a^2 - b^2)^{1/2} \,|(d_{5/2})^2; 4\rangle + a\,|(g_{7/2})^2; 4\rangle + b\,|d_{5/2}\, g_{7/2}; 4\rangle. \tag{3}$$

In the general case, off-diagonal elements could modify the magnetic moment considerably, and it might not be possible to derive a unique value for the magnitude of the admixture from the experimental g-factor. In this case the off-diagonal elements of the M1 operator vanish by the $\Delta\ell$ rule, and the g-factor is given by

$$\langle g_{2.083}\rangle = 1.92\,(1 - a^2 - b^2) + 0.491\, a^2 + 0.956\, b^2 \tag{4}$$

where the numerical coefficients are just the pure-configuration g-factors. Comparison with Eq. (2) yields an upper limit of 26% on the total admixture, or

$$a^2 + b^2 < 0.26 \tag{5}$$

FOOTNOTE AND REFERENCES

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1. L. S. Kisslinger and R. A. Sorensen, Mat. Fys. Medd. Dan. Vid. Selsk. 32 (1960) No. 9.
2. W. M. Currie, Nucl. Phys. 32 (1962) 574.
3. H. Frauenfelder, "Angular Correlation", in Beta- and Gamma-Ray Spectroscopy (Interscience, New York, 1955).