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Spin-parity of the 14.08 MeV level in ^{12}C†

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Employing the spin alignment obtained with inelastic α particle scattering at 0°, we have shown the J^π of the 14.08 MeV level in ^{12}C to be 4^+. The branching ratio of this level for α decay to the ^{8}Be ground state is $(9 \pm 3)\%$; however, this ratio could be affected by interference with inelastic scattering to the 3α continuum.

[NUCLEAR STRUCTURE ^{12}C measured α decay angular correlation from 14.08 MeV level, deduce $J^\pi = 4^+$.]

The spin and parity of the 14.08 MeV level in ^{12}C has been of interest for more than a decade. The interest originated when this level was assigned $J^\pi = 4^+$ and placed in the ground state rotational band.[1] Since that time, several experiments[2] have been performed involving this state, most of them consistent with $J^\pi = 4^+$. Indeed, in the most recent data compilation[2] for the $A = 12$ system, this level is given that spin and parity. The most compelling evidence for this assignment comes from the relative yields observed in one and two particle pickup reactions[3] in which the 14.08 MeV level is the final state. However, the most recent publication[4] on this subject argues that their observed differential cross section for inelastic α particle scattering as well as much of the previous data support a 3^- assignment to this level.

As we have recently brought into operation a large solid angle magnetic spectrograph[5] (14 msr), it is possible to approach this problem in a model independent fashion by measuring the angular correlation of α particles from aligned samples of this state which decay to the ^{8}Be ground state. The alignment is achieved by exciting the level via inelastic α particle scattering where the inelastically scattered α particle is detected at 0° (method II of Litherland and Ferguson[6]).

A 45 MeV α particle beam from the Princeton University AVF cyclotron is directed onto a 400 μg/cm^2 ^{12}C foil. The beam along with inelastically scattered ions passes through the defining slits of the magnetic spectrograph, as shown in Fig. 1. The beam is intercepted in a carefully positioned Faraday cup between the first and second dipole while particles of lesser rigidity are bent around onto the focal plane of the spectrometer. Considerable effort had to be expended to keep the background at the focal plane detector within tolerable limits. This was accomplished using antiscattering baffles around the Faraday cup. The acceptance angle of the spectrometer is sufficiently large that the multiple scattered beam ($\langle\theta\rangle_{\mathrm{rms}} = 0.6°$) from the target does not strike the spectrometer defining slits.

The detection system at the focal plane of the spectrometer consists of a resistive wire gas proportional chamber 60 cm in length which is backed by a long scintillation detector. The signals from the resistive wire in the proportional chamber provide position information as well as a measure of the energy loss in the gas. The scintillator signal is a rough measure of the total energy and can be used for particle identification. This latter feature was not required as better than 99% of the detected particles at 0° are α particles.

Bombarding an empty target holder with inside dimensions 2 cm × 1.75 cm, we observe 2×10^3 counts/100 keV μC in the range $30 \le E_\alpha \le 32$ MeV. Bombarding a 400 μg/cm^2 ^{12}C foil yields the position spectrum shown in Fig. 2(a) at 0° corresponding to 7 to 10 MeV excitation in ^{12}C, while Fig.

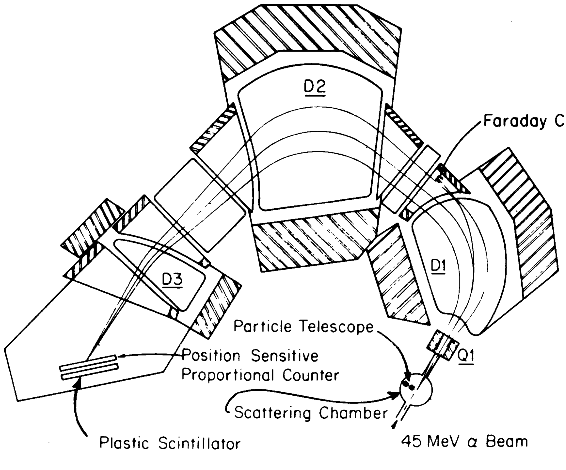

FIG. 1. Layout of the Princeton University QDDD magnetic spectrometer for a 0° experiment.

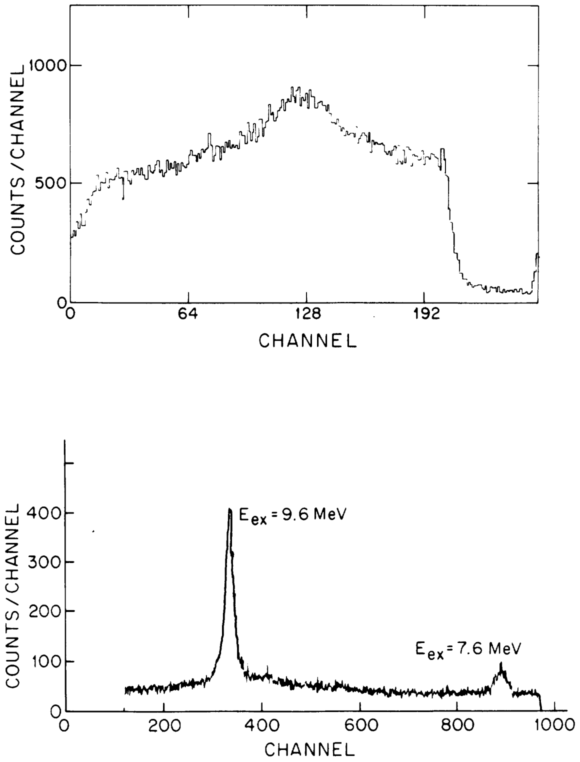

FIG. 2. Focal plane position spectrum of particles detected at 0° to an incident 45 MeV α particle beam. The target is ^{12}C and the spectrum corresponds to an excitation of 7–10 MeV in ^{12}C. (b) Same as (a) but with the spectrometer field set so that the spectrum corresponds to an excitation of 13–15 MeV in ^{12}C.

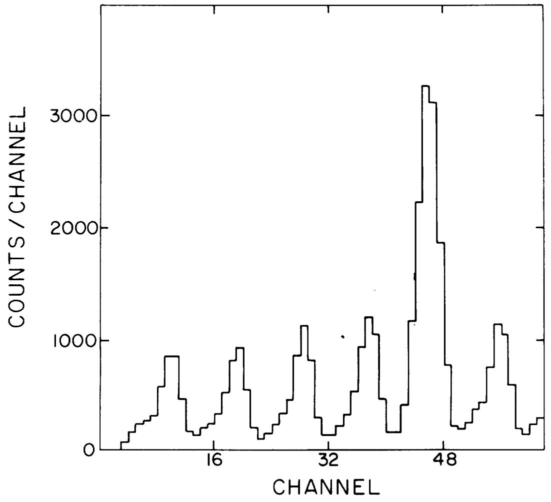

FIG. 3. Spectrum of time delays between the solid state detector and the scintillation detector in the plane of the QDDD magnetic spectrometer.

TABLE I. Expected energies of α particles from the decay of the 14.08 MeV level in ^{12}C to the ^{8}Be ground state.

θ_{lab} (deg)	$\theta_{\text{c.m.}}$ (deg)	E_{α_0} (MeV)
79	90	4.03–4.56
90	110	3.14–3.45
121	131	2.93–3.33
144	149	2.62–3.01

2(b) shows the spectrum for excitation energies between 13 to 15 MeV. The cross section for the 9.63 MeV level in ^{12}C corresponds to 20 mb/sr while that for the 14.08 MeV level is 5 mb/sr. These levels have natural widths of 34 and 245 keV, respectively. It is difficult to estimate how much of the continuum in the spectrum shown in Fig. 2(b) is associated with processes that originate in other than the target. Some continuum background from the target is expected as ^{12}C is unstable against breakup into 3α particles above 7.37 MeV. Hence, contribution to the yield under the peak due to the 14.08 MeV level can result from the ^{12}C$(\alpha, \alpha')3\alpha$ reaction where the α' continues forward at 0° or in a very inelastic collision ($Q < -20$ MeV) the α' scatters in a backward direction and one of the breakup α particles goes forward with sufficient energy to appear in the spectrum.

The 5.0 mb/sr cross section observed for the 14.08 MeV level is consistent with the hypothesis that this level has natural spin and parity, as unnatural parity states are strictly[7] forbidden at 0°.

As indicated in Fig. 1, a detector telescope consisting of two 150 mm surface barrier diodes is positioned in the scattering chamber. The front detector is 200 μm thick and the rear diode functions as a veto counter. This system subtends 15 msr. The front detector is operated in time coincidence with the scintillation counter at the focal plane of the magnetic spectrometer. The resulting spectrum of time delays observed between these counters is shown in Fig. 3. The periodic structure arises from the cyclotron rf modulation of the beam intensity. The time resolution is completely attributable to variations in flight time through the spectrometer due to different entrance angles. The true to accidental rate is seen to be 2 : 1.

As most previous work favored a 4^+ assignment, the detector telescope was positioned at angles corresponding to the maxima and minima associated with $[P_4(\cos\theta_{\text{c.m.}})]^2$ where $\theta_{\text{c.m.}}$ is measured relative to the beam direction. The energy of the α particle group associated with the decay of ^{12}C to the ^{8}Be ground state is well defined apart from

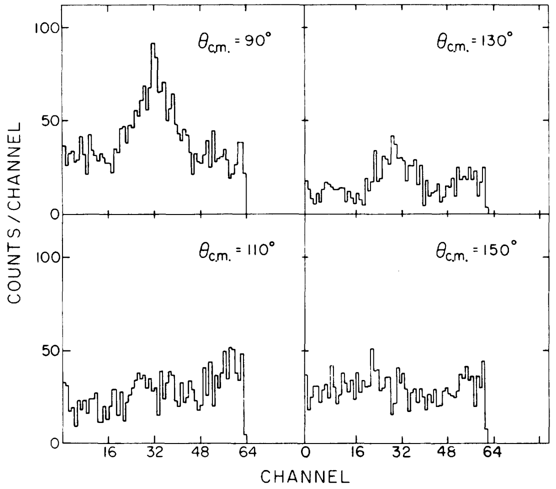

FIG. 4. Focal plane position spectrum in coincidence with α particles corresponding to decay to the ^{8}Be ground state.

the effects of the spread in the ^{12}C recoil direction, energy loss in the target, and the finite solid angle subtended by the detector telescope. The predicted energies and widths of this α particle group are listed in Table I. The position spectrum of particles at the focal plane of the magnetic spectrometer which are in time coincidence with this α particle group is shown in Fig. 4 as a function of telescope angle. The peak in the position spectrum associated with the excitation of the 14.08 MeV level is observed to be enhanced when the telescope is at 90° and 130° and little if any enhancement of the coincidence yield is noted with the telescope at 110° and 150°. The first two angles correspond to maxima in $[P_4(\cos\theta_{c.m.})]^2$ while the latter two are associated with minima. Figure 5 shows the coincidence yield to the 14.08 MeV peak as a function of the solid state detector angle and only $J = 4$ shows a reasonable fit. The fact that the yield at 90° is large shows that the J value must be even; thus $[P_2(\cos\theta)]^2$ and $[P_6(\cos\theta)]^2$ are also shown. Using expressions to be found in Ref. 6 we estimated $[P(m=1)]/[P(m=0)] < 0.02$. As $Y^0_L(\theta,\phi)$ has roots where $Y^1_L(\theta,\phi)$ is a maximum, our predicted angular distributions are little modified by including the $m = 1$ contribution.

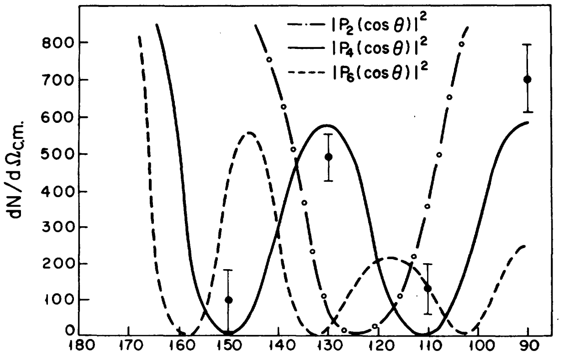

FIG. 5. Angular distribution of coincident events between particles in the 14.08 MeV group in the position spectrum and α particles corresponding to decay to the ^{8}Be ground state. The curves take account of finite solid angle effects.

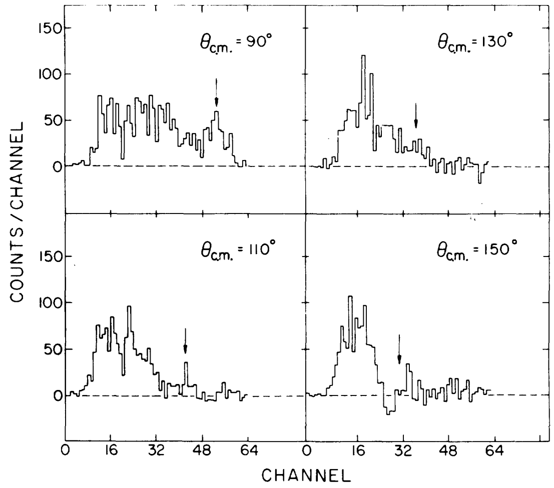

FIG. 6. Energy spectrum of particles in the solid state detector in time coincidence with particles in the 14.08 MeV group in the QDDD position spectrum.

Figure 6 shows the energy spectrum observed in the particle telescope in coincidence with particles in the 14.08 MeV group in the quadrupole-dipole-dipole-dipole (QDDD) as a function of the angular positions of the solid state detector telescope. These spectra are generated by subtracting the coincidence spectrum associated with channels 20 to 40 from that associated with channels 1 to 20 as noted in Fig. 4. The α particle group associated with decay through the ^{8}Be ground state is evident only in the spectra obtained at 90° and 130°.

The branching ratio associated with decay through the ^{8}Be ground state as determined by a least squares fit of the $J = 4$ angular distribution to the data yields $\Gamma_0/\Gamma = (9 \pm 3)\%$ which is consistent with previous workers.[2,4] However, the observed angular distribution ($\chi^2 = 1.9$) does not seem to be that associated solely with the decay of an aligned 4^+ state and may reflect interference of this decay with a part of the continuum breakup. This interference would affect our determination of Γ_0/Γ but would have no influence on the 4^+ assignment.

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