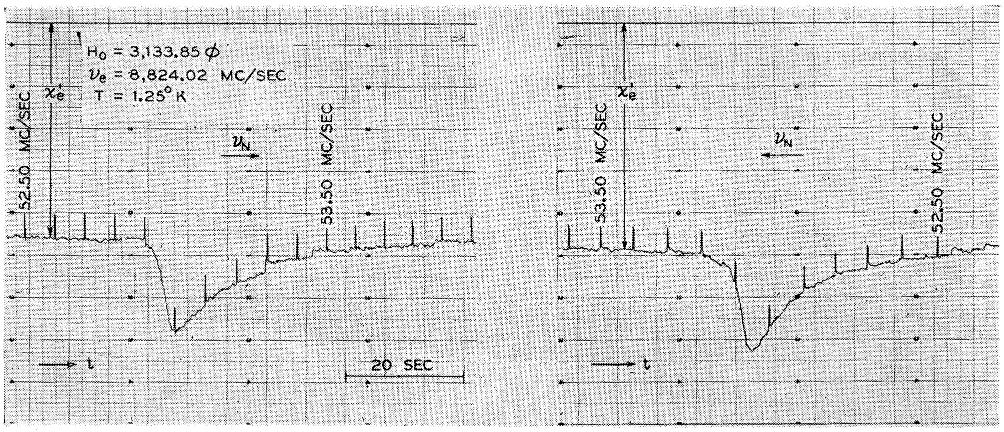

FIG. 2. Electron spin resonance signal in phosphorus-doped silicon. Small vertical lines on trace represent frequency markers of the rf field which is superimposed on the microwave field. A similar trace was obtained at a frequency 11.59 Mc/sec higher.

In either case the population difference in levels A and A' has been increased and thereby the electron spin resonance signal enhanced.

The experimental setup and the phosphorus-doped silicon sample were similar to the one described earlier[2] with the exception that 100-cps magnetic field modulation was used. The magnetic field was adjusted to correspond to the resonance condition of the low-field line ($m_I=+\frac{1}{2}$). Figure 2 is the recorder tracing of the electron spin resonance signal. It shows clearly the enhancement of the signal when the frequency corresponding to the nuclear transitions is being traversed. This enhancement decays with a characteristic time depending on the rate at which the levels A, A' are being saturated. This accounts for the observed asymmetry of the line. A similar line was observed at a frequency 11.59±0.02 Mc/sec higher corresponding to nuclear transitions between levels A' and B' (see Fig. 1). From this frequency difference, one may easily calculate g_I for phosphorus [see reference 1, Eq. (2)]. The value obtained is $g_I=2.265\pm0.004$ which agrees with the accepted value[3] of 2.2632±0.0004.

Since this method yields a value of g_I without having to know the wave function of the electron associated with the paramagnetic center, it may be used either to determine an unknown nuclear g_I or as an analytical tool to identify impurities.

The method is also applicable to uses in which the hyperfine interaction $a(\mathbf{I}\cdot\mathbf{J})$ is small in comparison to the electron line width and therefore no structure can be observed in a single-frequency spin resonance experiment. Such a case is, for example, lithium-doped silicon, in which Honig and Kip[4] first observed an unresolved electron spin resonance line. By performing the same experiment as in the phosphorus-doped silicon sample described before, we were able to observe an enhancement of the electron spin resonance line at the frequencies of 4.89 Mc/sec and 5.74 Mc/sec with an external magnetic field of 3217 oersteds. Since for this case $a(\mathbf{I}\cdot\mathbf{J})<g_I\mu_0H$, we expect the two frequencies $\nu_{1,2}$ to occur at

$$h\nu_{1,2}\simeq g_I\mu_0H\pm\tfrac{1}{2}a.$$

This yields for the hyperfine interaction constant $a=0.85\pm0.01$ Mc/sec as compared with the theoretical estimate of Kohn and Luttinger[5] of 0.5 Mc/sec. We also obtained lines arising from the interaction of the electron with the Si^{29} nuclei. They are presently being analyzed in more detail and may prove to be a convenient way of getting the electron wave functions at different lattice points.

Another system to which the double-resonance method has been applied is F centers in KCl. An unresolved line was first observed by Hutchison[6] and investigated in greater detail by Kip *et al.*[7] We were able to resolve different sets of lines which presumably arise from the interaction of the electron with the potassium and chlorine nuclei. A more detailed analysis is being prepared for publication.

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Gamma-Ray Branching Ratio of the 3.95-Mev Level in N^{14}

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IN the course of a study of He^3-induced reactions on C^{12},[1] the gamma-ray branching ratio of the 3.95-Mev level in N^{14} has been measured. The results of this

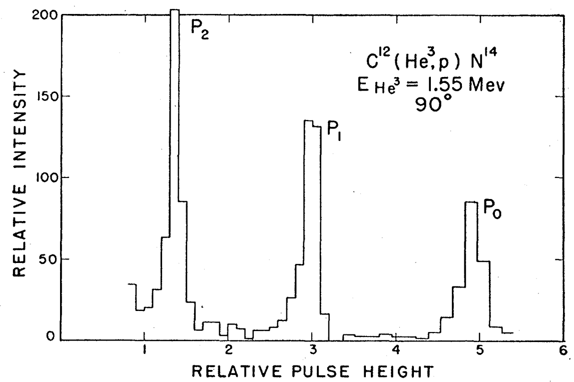

FIG. 1. Proton spectrum.

measurement are reported here because of their relevance to current calculations on the anomalously long C^{14} beta-decay lifetime.[2,3] An attempt to measure this branching ratio was made by Hird *et al.*[4] employing the reaction $C^{13}(p,\gamma)N^{14}$. No evidence was obtained for a 3.95-Mev gamma ray and an upper limit of 5% compared to the 1.64-Mev transition was estimated.

In the present experiment, He^3 particles accelerated in the Chalk River electrostatic generator to an energy of 1.55-Mev bombarded thin carbon targets. Protons from the $C^{12}(He^3,p)N^{14}$ reaction were detected at an angle of 270° to the beam axis with a CsI(Tl) crystal and Dumont 6292 photomultiplier. The gamma rays emitted both directly and in coincidence with a selected proton group were measured in a 5-in. diameter by 4-in. long NaI(Tl) crystal and a Dumont 6364 photomultiplier. This gamma-ray detector could be rotated from 0° to 90° to the beam axis in the plane containing this axis and the proton detector.

The proton spectrum is shown in Fig. 1 where the proton groups P_0, P_1, and P_2 leave N^{14} in its ground, 2.31-Mev, and 3.95-Mev state, respectively. Figure 2 shows the direct spectrum of gamma rays and the spectrum in coincidence with the proton group feeding the 3.95-Mev level observed at 90°. A similar pair of spectra were taken with the gamma counter at 0° to the beam axis. The 4.91-Mev gamma ray seen in the direct spectrum results from a proton group leaving N^{14} in an excited state of this energy. This proton group was of too low an energy to traverse a foil covering the CsI crystal (installed to prevent elastically scattered He^3 particles from being counted) and hence is not observed in Fig. 1.

The coincidence spectra show the gamma-ray cascade of energies 1.64 and 2.31 Mev and a weak cross-over transition of 3.95 Mev. In addition there is a small contribution due to random coincidences from the 4.91-Mev gamma ray observed in the direct spectrum. The relative areas at the two angles under the total absorption peaks of the 1.64- and 2.31-Mev gamma rays showed that the 2.31-Mev gamma-ray distribution was spherically symmetric while that of the 1.64-Mev gamma ray had a 10% positive $P_2(\cos\theta_\gamma)$ term. This is consistent with the assignments of 0+ and 1+ respectively to the levels in N^{14} at 2.31 and 3.95 Mev. To obtain the relative intensity of the 3.95- and 1.64-Mev gamma rays, the former had to be corrected for the tail of the 4.91-Mev chance coincidence spectrum and for contributions due to the simultaneous entry into the crystal of a 1.64- and a 2.31-Mev gamma ray. Such a summation spectrum, however, would not show a total absorption and single-escape peak of comparable intensity since the single-escape peak is quite small in the spectrum of 1.64- and 2.31-Mev gamma rays. The contribution to the observed spectrum due to summation can be calculated since the absolute efficiency of the gamma-ray spectrometer for 1.64- and 2.31-Mev gamma rays is measured directly in such a coincidence spectrum. The correction at both 0° and 90° amounted to about 15%. The contribution due to chance coincidences from the 4.91-Mev gamma ray was subtracted by fitting a curve as shown in Fig. 2 to the points beyond the 3.95-Mev peak having the same shape as observed in the direct spectrum.

While this measurement at two angles completely defines the angular distributions in the plane (since the total angular momenta of states involved in N^{14} are either 0 or 1), it does not account for possible azimuthal

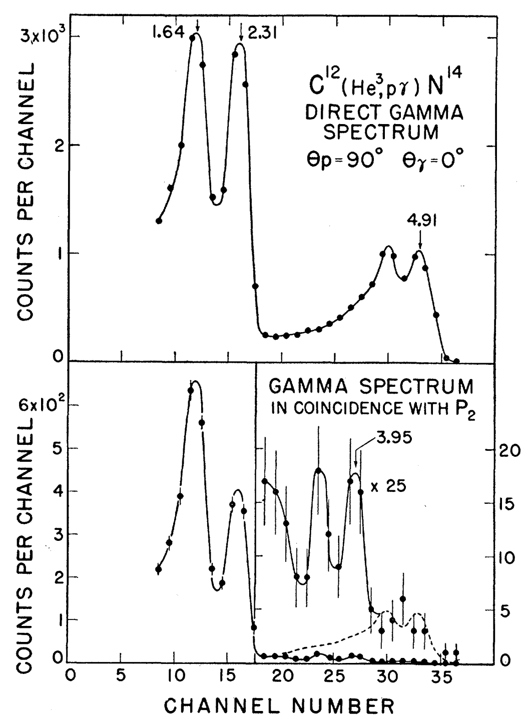

FIG. 2. Direct gamma-ray spectrum and gamma-ray spectrum in coincidence with the proton group leading to the 3.95-Mev level in N^{14}.

variations. The apparatus did not permit either counter to be moved azimuthally about the beam axis and it has been arbitrarily assumed that such a correlation is azimuthally isotropic. An experiment to check this point will be undertaken. The ratio of 3.95-Mev cross-over transitions to 1.64-Mev transitions, corrected as described, was $4.3 \pm 0.8\%$.

Since both transitions can be $M1$, the 3.95-Mev transition would be 14 times as intense as that for the 1.64 Mev if the energy-cubed law alone governed. Recently Elliott[2] has proposed an explanation for the long beta lifetime of C^{14} which requires that the branching ratio of the 3.95-Mev level in N^{14} be $\sim 1\%$ by cross-over transitions which he finds would be predominantly $E2$. He remarks that any collective motion, which he did not consider, would enhance the $E2$ transition and so increase the branching ratio. The problem of C^{14} and N^{14} has also been considered by Visscher and Ferrell,[3] who predict a branching ratio of 3.9% without any requirement of collective motion.

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Regularities in the Level Schemes of Heavy Even-Even Nuclei

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It has been pointed out recently[1] that at $A \sim 150$ an abrupt transition takes place in the nature of the level schemes of even-even nuclei and that this transition is solely governed by the number of neutrons in the nucleus. For $N \leq 88$ we find that the energy of the first excited state $E_1 > 300$ kev and that $E_2/E_1 \sim 2.2$, where E_2 is the energy of the second excited state with even spin and parity. From the study of decay schemes one finds that this state has in most cases the character 2+, somewhat less frequently 4+, and rarely 0+. This type of level scheme and the observed transition probabilities and multipole mixtures have been interpreted in terms of the Bohr-Mottelson model in the region of weak to moderate coupling[1] and also in terms of a Bohr-Mottelson strong coupling model with "γ-unstable potential."[2] We shall call here this pattern the "near-harmonic pattern," in contrast to the well-known rotational pattern, which occurs for $N \geq 90$ and is characterized by the spin sequence 0+, 2+, 4+, $\cdots$, $E_1 < 125$ kev, and E_2/E_1 approaching 3.33 with increasing neutron number. An explanation for the dramatic increase in nuclear deformation between

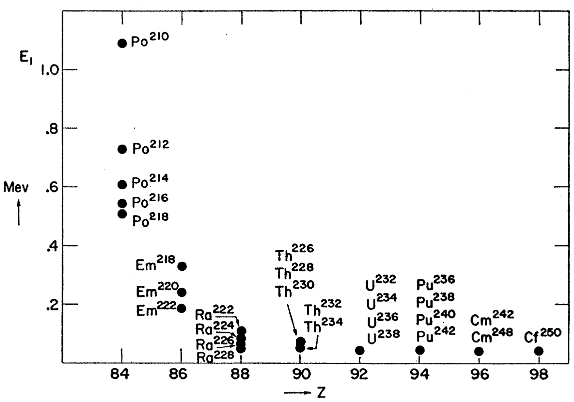

Fig. 1. Energy E_1 of first excited states of nuclei with $Z > 82$ and $N \geqslant 126$, plotted against Z. For $Z \leqslant 88$, the addition of 2 protons produces a greater change in E_1 than the addition of 2 neutrons (except when the neutron number is magic).

$N = 88$ and $N = 90$ has been suggested by Mottelson and Nilsson.[3]

Since it is known that another rotational region exists among the heavy nuclei,[4] it seemed interesting to find out whether it, too, is preceded by a near-harmonic region. In Fig. 1 the energies of the first excited states of even-even nuclei with $Z > 82$ and $N \geq 126$ are plotted against the number of protons in the nucleus, showing a rapid decrease with increasing Z. It is seen that in this region E_1 depends more strongly on the *proton* number than on the neutron number, as indicated by the isobar pairs $Po^{218}-Em^{218}$ and $Em^{222}-Ra^{222}$. The question arises whether, if a near-harmonic region exists here, the transition to the rotational region is also governed by the number of protons, and if so, which are the critical proton numbers. It is known that several of the Ra isotopes possess a fairly well-developed rotational pattern.[4] Ra^{222}, the radium isotope which has the smallest number of neutrons and which is furthest removed from the pure rotational nuclei, has a second excited even spin state of character 4+, and an energy ratio $E_2/E_1 = 2.75$.[5] This ratio falls considerably above the range of E_2/E_1 ratios observed for the near-harmonic pattern; hence we conclude that the rotational pattern starts at $Z \leq 88$. Since no higher excited state had been established beyond the first 2+ state for any of the Em isotopes,[6] it seemed desirable to find at least one second excited state.

Harbottle, McKeown, and Scharff-Goldhaber[7] have now studied the γ rays following the α emission from Ra^{226} and have established that besides the well-known 2+ state at 188 kev there exists in Em^{222} a second excited state at 448 kev. They confirmed the existence of a weak γ transition of 260 kev previously observed by Stephens[8] in coincidence with Ra^{226} α rays and found that it coincided with the 188-kev γ transition. No 448-kev γ rays were observed, the upper limit being $\sim 1/20$ of the intensity of the 260-kev transition. The character of the 448-kev state was not directly