If one considers the nucleus in a simple two-fluid model, with densities ρ_p and ρ_n, the Steinwedel-Jensen model only accounts for the interaction with the difference density $\rho_p - \rho_n$. But the electron also interacts with the total density, $\rho = \rho_p + \rho_n$ (although the dipole component would presumably be weak), and it is the deformation of ρ which is commonly pictured as leading to fission. If the contribution of such an interaction were significant, the electron could serve as a valuable probe of the dynamical process of fission. Calculations employing such a model are in progress.

Finally we would like to point out the need for more experiments in electrofission and photofission particularly at high energy.

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[1] Y. N. Ranyuk and P. V. Sorokin, Yadern. Fiz. 5, 531 (1967) [translation: Soviet J. Nucl. Phys. 5, 377 (1967)].

[2] H. R. Bowman, R. C. Gatti, R. C. Jared, G. Kiliam, L. G. Moretta, S. G. Thompson, M. R. Croissiaux, J. H. Heisenberg, R. Hofstadter, L. M. Middleman, and M. R. Yearian, Phys. Rev. 168, 1396 (1968), and J. Phys. Soc. Japan 24, 545 (1968).

[3] E. K. Hyde, The Nuclear Properties of Heavy Elements (Prentice Hall, Inc., Englewood Cliffs, N.J., 1964), Vol. III.

[4] D. S. Onley, J. T. Reynolds, and L. E. Wright, Phys. Rev. 134, B945 (1964), and earlier work cited therein.

[5] S. T. Tuan, L. E. Wright, and D. S. Onley, Nucl. Instr. Methods 60, 70 (1968).

[6] K. Alder, A. Bohr, T. Huus, B. Mottelson, and A. Winther, Rev. Mod. Phys. 28, 432 (1956).

[7] T. deForest and J. D. Walecka, Advan. Phys. 15, 1 (1966).

[8] R. H. Dalitz and D. R. Yennie, Phys. Rev. 105, 1598 (1957).

[9] V. H. Steinwedel and J. H. D. Jensen, Z. Naturforsch. 5a, 413 (1950).

[10] H. Bethe and W. Heitler, Proc. Roy. Soc. (London), Ser. A 146, 83 (1934).

[11] L. Katz, A. P. Baerg, and F. Brown, in Proceedings of the Second United Nations International Conference on the Peaceful Uses of Atomic Energy (United Nations, Geneva, Switzerland, 1958).

[12] W. C. Barber, Phys. Rev. 111, 1642 (1958).

LOWEST $T=2$ LEVEL IN ^{28}Si OBSERVED AS A HIGHLY FORBIDDEN COMPOUND NUCLEUS RESONANCE IN ^{24}Mg + α REACTIONS*

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The lowest $T=2$ level in the self-conjugate nucleus ^{28}Si has been observed in resonance reactions initiated by ${}^{24}\mathrm{Mg}+\alpha$ ($\Delta T=2$) but not in resonance reactions initiated by ${}^{27}\mathrm{Al}+p$ ($\Delta T=1$).

Within the past two years low-lying $T=2$ levels in self-conjugate, light nuclei (N, Z), which had been seen as residual states,[1,2] have been observed[3-5] as compound-nucleus resonances in the isospin forbidden reactions initiated by $p+(N, Z-1)$. However, attempts made over the past year to observe the lowest $T=2$ state in ^{28}Si as a compound-nucleus resonance in ${}^{27}\mathrm{Al}+p$ reactions have been unsuccessful.[6] Recently the level has been observed[7] as a final state in the isospin-allowed reaction ${}^{30}\mathrm{Si}(p,t){}^{28}\mathrm{Si}_{T=2}{}^*$, and has been found to decay predominantly to ^{24}Mg(ground state) + α. Following acquisition of a negative helium-ion source, we observed this level as a compound-nucleus resonance in the twice T-forbidden capture reaction ${}^{24}\mathrm{Mg}(\alpha,\gamma){}^{28}\mathrm{Si}_{T=1}{}^*(\gamma){}^{28}\mathrm{Si}_{T=0}$ and the four-times T-forbidden scattering reactions ${}^{24}\mathrm{Mg}(\alpha,\alpha_0){}^{24}\mathrm{Mg}$ and ${}^{24}\mathrm{Mg}(\alpha,\alpha_1){}^{24}\mathrm{Mg}^*$. No resonance was seen in the once forbidden reaction ${}^{27}\mathrm{Al}(p,\gamma){}^{28}\mathrm{Si}_{T=1}{}^*(\gamma){}^{28}\mathrm{Si}_{T=0}$, or in ${}^{27}\mathrm{Al}(p,p_0){}^{27}\mathrm{Al}$, ${}^{24}\mathrm{Mg}(\alpha,p_0){}^{27}\mathrm{Al}$, or ${}^{24}\mathrm{Mg}(\alpha,p_1){}^{27}\mathrm{Al}^*$.

As in the earlier experiments,[3,4] the gamma decay of the 0^+, $T=2$ level of ^{28}Si was found to proceed via γ-ray cascades through bound 1^+, $T=1$ levels lying in the region of excitation from 10.7 to 11.4 MeV. The $T=2$ level was located by observing a resonance in an unresolved group of γ rays with an energy of $\approx$11 MeV. The γ rays were detected with the Stanford University 24-cm NaI assembly.[8] Figure 1 shows the yield curves of γ_0, γ_1, and the 11-MeV group, along with on- and off-resonance γ-ray spectra, obtained by bombarding a 10-keV ^{24}Mg target on a gold backing with a beam of α particles. The apparent slight resonance in γ_0 is attributed to solid-angle summing of the resonant cascade γ rays. The yield in the on-resonance γ spectrum at $E_\gamma \approx 9$ MeV is presumably due to transitions from the $T = 1$ states to the first excited state of ^{28}Si at 1.78 MeV.

The observed resonance energy of $E_\alpha = 6.115 \pm 0.003$ MeV, corresponding to $E_x = 15.221 \pm 0.005$ MeV, is in good agreement with the value of $E_x = 15.206 \pm 0.025$ MeV previously measured.[7] The angular distribution of the 11-MeV group of γ rays, shown in the insert of Fig. 1, is isotropic, as required by the assignment of $J = 0$ to the resonant level. Also shown in Fig. 1 is the yield curve for a γ ray of energy ≈11 MeV produced by the reaction ^{27}Al$(p, \gamma)^{28}$Si. The strong resonance at $E_p = 3.788 \pm 0.003$ MeV, corresponding to a level at $E_x = 15.234 \pm 0.005$ MeV, is a resonance detected previously[6] for which the γ ray was assigned to the 10.6-MeV transition to the 4^+ state at 4.6 MeV in ^{28}Si. The relative uncertainty in energy between the ^{27}Al$+p$ excitation curve and the ^{24}Mg$+\alpha$ excitation curve is estimated to be 0.003 MeV, based on the Q value[9] of 1.6017 ± 0.0007 MeV for the reaction ^{27}Al$(p, \alpha)^{24}$Mg.

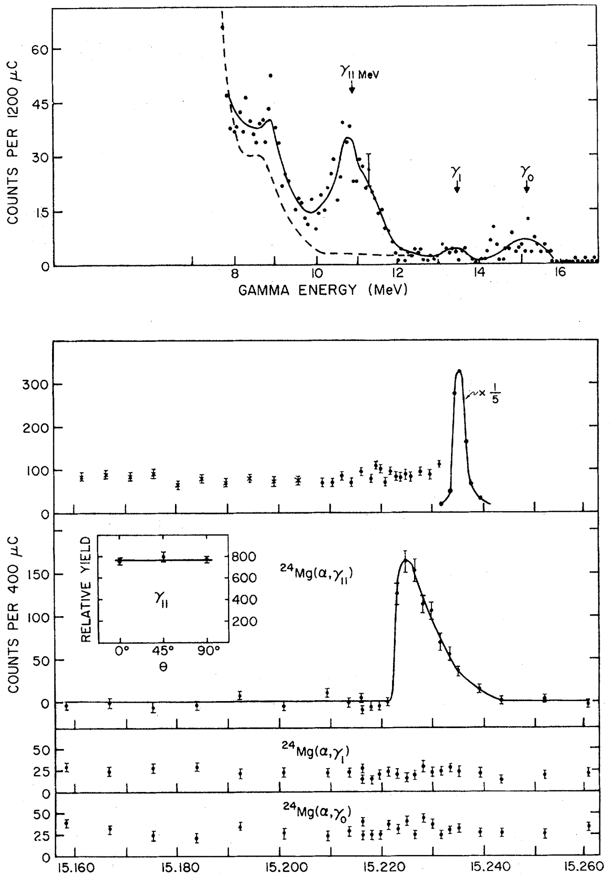

FIG. 1. Bottom three curves: the yields of γ_0, γ_1, and the 11-MeV γ-ray group, as a function of excitation energy in ^{28}Si, produced by the reaction ^{24}Mg$(\alpha, \gamma)^{28}$Si (10-keV ^{24}Mg target). Insert: the on-resonance angular distribution of the 11-MeV group. Top curve: the solid line is the sum of three partial gamma-ray spectra at the resonance in ^{24}Mg$(\alpha, \gamma)^{28}$Si; the dashed line is the sum of off-resonance spectra. Second curve from top: the yield of γ rays near $E_\gamma = 11$ MeV from the reaction ^{27}Al$(p, \gamma)^{28}$Si; the dots are for a 2-keV ^{27}Al target, and the crosses for a 5-keV target. The error bars shown are statistical, and the collected charge is for singly charged particles.

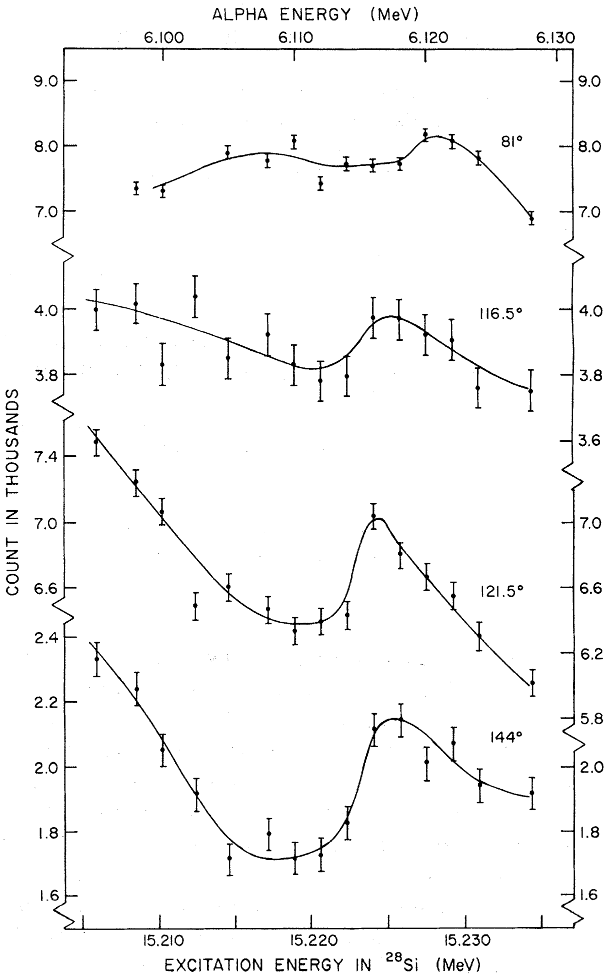

FIG. 2. The elastic scattering of alpha particles at four angles, observed with a ^{24}Mg target 6 keV thick, evaporated on a thin carbon backing. The energy scales in Figs. 1 and 2 are derived from the nominal accelerator calibration.

The accelerator was calibrated with the $^{19}F(p, n)^{19}Ne$ threshold[10] at $E_p = 4.2343 \pm 0.0008$ MeV and the $^{24}Mg(\alpha, \gamma)^{28}Si$ resonance[9] at $E_\alpha = 3.1998 \pm 0.0010$ MeV.

The particle groups from the $^{24}Mg + \alpha$ reactions were observed in a 60-cm scattering chamber at several angles. The elastic scattering curves at four angles are shown in Fig. 2. These four laboratory angles 81°, 116°, 144°, and $121\frac{1}{2}°$ correspond to the zeros of P_{odd}, P_2, P_4, and P_6 (approximately). Observation of the resonance at all four angles supports the assignment of 0^+ to the resonant state. A resonance was also observed in $^{24}Mg(\alpha, \alpha_1)^{24}Mg^*$ at $121\frac{1}{2}°$ and, with lesser certainty, at $104\frac{1}{2}°$. Target contaminants obscured the α_1 peak at the backward angles of 144° and $156\frac{1}{2}°$, and the resonance was not observed at other angles. No effect was observed in $^{24}Mg(\alpha, p_0)^{27}Al$ or $^{24}Mg(\alpha, p_1)^{27}Al^*$.

From the γ-ray yield curve of Fig. 1 we can set an upper limit of 2 keV for the total width of the state. From the nonobservation of the resonance in γ rays produced by $^{27}Al + p$ we obtain $\Gamma_p/\Gamma_\alpha < 0.08$, in agreement with previous work.[7] From the observed strength of the 11- and 9-MeV groups we estimate $\Gamma_\alpha \Gamma_\gamma / \Gamma = 1.25^{+0.25}_{-0.45}$ eV, if we assume a target composition of 100% ^{24}MgO, where the asymmetric error reflects the uncertainty in the target composition. This value, combined with the previously reported measurement[7] of $\Gamma_\alpha/\Gamma = 0.72 \pm 0.11$, gives $\Gamma_\gamma = 1.7^{+0.4}_{-0.7}$ eV, a value comparable with that obtained in ^{24}Mg and ^{20}Ne.[3,4] From the nonobservation of a resonance in $^{24}Mg(\alpha, \gamma_1)^{28}Si^*$, we can place an upper limit of $\Gamma_{\gamma_1} < 0.03\ \Gamma_\gamma$ on an isospin-violating $\Delta T = 2$ γ decay to the 2^+ state at 1.78 MeV in ^{28}Si.

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[1] J. Cerny, R. H. Pehl, and G. T. Garvey, Phys. Letters 12, 234 (1964).

[2] E. Adelberger and A. B. McDonald, Phys. Letters 24B, 270 (1967).

[3] F. Riess, W. J. O'Connell, D. W. Heikkinen, H. M. Kuan, and S. S. Hanna, Phys. Rev. Letters 19, 367 (1967).

[4] H. M. Kuan, D. W. Heikkinen, K. A. Snover, F. Riess, and S. S. Hanna, Phys. Letters 25B, 217 (1967).

[5] R. Bloch, R. E. Pixley, and P. Truöl, Phys. Letters 25B, 215 (1967).

[6] H. M. Kuan, F. Riess, K. A. Snover, D. W. Heikkinen, D. C. Healey, and S. S. Hanna, Bull. Am. Phys. Soc. 13, 884 (1968).

[7] R. L. McGrath, J. C. Hardy, and J. Cerny, Phys. Letters 27B, 443 (1968).

[8] M. Suffert, W. Feldman, J. Mahieux, and S. S. Hanna, Nucl. Instr. Methods 63, 1 (1968).

[9] A. Rytz, H. H. Staub, H. Winkler, and F. Zamboni, Nucl. Phys. 43, 229 (1963).

[10] Jerry B. Marion, Rev. Mod. Phys. 38, 660 (1966).