source of power, and a transmission-type cavity was used. The microwave absorption was measured in all cases by the magnetic field modulation method.

Two orientations of the plane of the sample with respect to the external field were used in the 1.2-cm measurements, one parallel to the field in fields of about 3000 oersteds and the other normal to the field in fields of about 22 000 oersteds. The two resonance conditions are given by:[2]

$$\omega=\gamma[H_0(H_0+B_s)]^{\frac{1}{2}},$$

and

$$\omega=\gamma(H_0-B_s),$$

where H_0 is the external field for maximum absorption corrected for finite sample thickness, B_s the saturation induction, and $\gamma=ge/2mc$. From these two equations B_s and g can be calculated. The 6-mm and 3-cm measurements were made with the plane of the sample parallel to the external field in fields of about 10 000 and 800 oersteds respectively and the g-value calculated using the value of B_s given by the 1.2-cm measurements. The results are given in Table I. Values of B_s measured by a force method on samples of the same composition are given for comparison. The fields were measured by a rotating coil fluxmeter calibrated with a free radical compound to an accuracy of 1 percent. The demagnetization factor correction of several hundred oersteds applied to H_0 in the 3-cm measurements limits the accuracy of these measurements to about 5 percent.

TABLE I. Summary of results. B_s is the saturation induction in kilogauss. ΔH is the full width between points of maximum slope in oersteds. $\perp$ and $\parallel$ refer to the orientation of the plane of the sample with respect to the external field.

		Percent nickel			
		36	40	44	48
1.2 cm	g	2.12	2.14	2.14	2.13
	B_s	15.0	15.7	15.7	16.3
	$\Delta H_\perp$	225	200	200	175
	$\Delta H_\parallel$	125	125	125	125
6 mm	g	2.10	2.08	2.11	2.08
	$\Delta H_\parallel$	250	250	250	250
3 cm	g	2.2	2.2	2.3	2.3
	$\Delta H_\parallel$	120	120	90	90
Force method	B_s	15.2	15.7	16.2	16.0

The width of the resonance lines is surprisingly narrow in contrast to the widths reported for spheres in colloidal suspension.[1] The width of the 3-cm lines corresponds to a half-width at half-power points of from 100 to 80 oersteds for a Lorentzian curve, compared to 1000 to 250 oersteds reported for the colloidal spheres.[1] These are believed to be the sharpest ferromagnetic resonance lines to be reported for metals. The anisotropy fields are quite low in these alloys, $2K_1/M_s$ varying from 35 to 16 oersteds, thus their contribution to the line width is negligible.

It is seen that the bulk measurements here reported give no sign of the variation in g value with changing nickel concentration as seen in the colloidal spheres. The discrepancy might lie in the fact that it is difficult to determine g values accurately from very broad lines such as Bagguley reports.[1]

We should like to express our thanks to Professor C. Kittel for suggesting this experiment and for several helpful discussions; to Professor A. F. Kip for many helpful suggestions regarding the measurements; to Mr. Tom Hazelett for annealing the samples; and to Mr. Glen Wagoner for his assistance with the 3-cm measurements. The metallurgical work and magnetic measurements were made at the Westinghouse Research Laboratories and the ferromagnetic resonance experiments were carried out at the University of California.

* This research was supported in part by the U. S. Office of Naval Research and the U. S. Signal Corps.

1 D. M. S. Bagguley, Proc. Phys. Soc. (London) **A66**, 765 (1953).
2 C. Kittel, Phys. Rev. **73**, 155 (1948).

Resonances in the Proton Bombardment of C^{14}

G. A. BARTHOLOMEW, F. BROWN, H. E. GOVE, A. E. LITHERLAND, AND E. B. PAUL
Physics Division, Atomic Energy of Canada Limited, Chalk River Laboratories, Chalk River, Canada
(Received September 20, 1954)

THE $C^{14}(p,\gamma)N^{15}$ reaction has been studied from 0.25 to 1.8 Mev by means of the Chalk River electrostatic accelerator. We wish to report a broad resonance observed in this reaction at a proton energy of 1.50 Mev which has not been reported in studies of the $N^{14}(n,n)$, $N^{14}(n,p)$, or $C^{14}(p,n)$ reactions.[1] Targets of elemental carbon, containing 25 percent C^{14} on tantalum backings, were prepared by heating the backings by induction to a bright red heat in the presence of CO gas containing radioactive carbon.

The yield curve of the ground state γ ray between proton energies of 0.9 and 1.7 Mev is shown in Fig. 1. These results were obtained in two experiments using two NaI(Tl) crystals 2 inches long by 2 inches in diameter mounted at angles of 0° and 90° to the direction of the proton beam in the first experiment and at angles of 143° and 90° in the second experiment. The neutrons from the $C^{14}(p,n)N^{14}$ reaction were also observed at 90° in each experiment. They were detected in a BF_3 counter surrounded with paraffin. The γ-ray yield curve has also been observed at 90° by Spearman, Hudspeth, and Morgan,[2] and the neutron yield curve by Roseborough, McCue, Preston, and Goodman.[3] The γ-ray yield exhibits a broad resonance with a maximum near a proton energy of 1.5 Mev. This resonance is only just discernible in the yield curves of the $C^{14}(p,n)N^{14}$ and the $N^{14}(n,p)C^{14}$ reactions where presumably it is

responsible for the background between the resonances at 1.31 and 1.67 Mev. The γ-ray yield curves clearly show evidence of interference between the broad resonance and those at 1.17 Mev and 1.31 Mev. The interference pattern is a function of angle at the 1.17-Mev resonance but is independent of angle at 1.31 Mev.

The angular distributions of the neutrons at all three resonances and of the ground state γ ray at the 1.31- and 1.50-Mev resonances were all isotropic while that of the ground state γ ray at 1.17 Mev showed a term proportional to $\cos\theta$. The isotropy of the neutron angular distribution at 1.17 and 1.31 Mev has also been observed elsewhere.[4] Since the 1.31-Mev resonance is known from the neutron scattering measurements[5] to be formed by s-wave neutrons, it may be deduced from the present results that the 1.31- and 1.50-Mev resonances are both $\frac{1}{2}+$ and that the 1.17-Mev resonance is probably $\frac{1}{2}-$ ($\frac{3}{2}-$ is also possible but less likely).

Estimates of total width, Γ, neutron width, Γ_n, proton width, Γ_p, and the partial width for the emission of the ground-state γ ray, $\Gamma_\gamma(\gamma_0)$, obtained from the yield curves are given in Table I. In estimating $\Gamma=475 \pm 25$ kev and $E_r=1.50\pm0.05$ Mev for the broad resonance, the γ-ray data were fitted with a single-level Breit-Wigner curve including the effect of the Coulomb barrier and ignoring the interference effects near the narrow resonances. With Γ and E_r fixed in this way, the (p,n) yield curve was analyzed to give the neutron yield of the broad resonance. The neutron counter efficiency at 1.31 Mev was obtained by assuming that the neutron yield obtained at this resonance is that computed by detailed balance from the known absolute yield of the $N^{14}(n,p)C^{14}$ reaction.[6] This absolute efficiency, when used to compute Γ_n and Γ_p for the other neutron resonances, leads to results in fair agreement with those obtained from neutron scattering.[5]

TABLE I. Resonance properties of N^{15}. The proton energy at resonance is given in the first column; the spin and parity in the second; and the total width, neutron width, proton width, and partial width for the emission of the ground state gamma ray are given in the third, fourth, fifth, and sixth columns respectively.

E_r Mev	J	Γ kev	Γ_n kev	Γ_p kev	$\Gamma\gamma(\gamma_0)$ ev
1.17	$\frac{1}{2}-$	12	1.6	10.4	0.25
1.31	$\frac{1}{2}+$	41	33.	8.	2.3
1.50	$\frac{1}{2}+$	475	5.	470.	28.

The properties of the broad state strongly suggest a nearly single-particle motion for the odd proton. The proton width is approximately equal to the single-particle width for s states defined by Lane,[7] while the value of $\Gamma_\gamma(\gamma_0)$ is about $\frac{1}{10}$ of the value given by the Weisskopf and Moszkowski single-particle formula.[8] It has been pointed out[9] that the proton bombardment of C^{14} produces excited states in N^{15} with isotopic spin quantum numbers $T=\frac{1}{2}$ and $\frac{3}{2}$ and therefore, since decay of $T=\frac{3}{2}$ states by neutron emission is forbidden at low bombarding energies while radiation is allowed, it may be possible to distinguish such states by com-

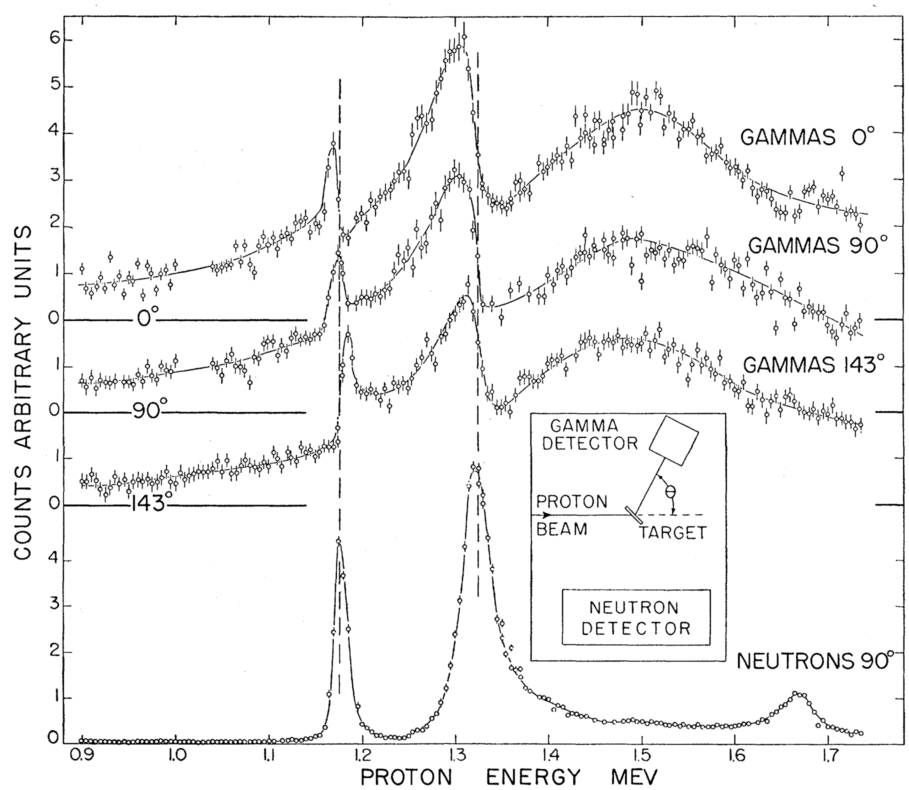

FIG. 1. Yield curves for the reaction $C^{14}(p,\gamma_0)N^{15}$ at three angles 0°, 90°, and 143° and for the reaction $C^{14}(p,n)N^{14}$ at 90° to the proton beam. The ordinate scales are shifted for comparison. The target arrangement is shown schematically in the inset.

paring the neutron and γ-ray yields. The calculated[10] energy of the first $T=\frac{3}{2}$ state in N^{15} (corresponding to the ground state of C^{15}) is 10.9 Mev. For the 1.50-Mev resonance at an excitation energy of 11.54 Mev the ratio of Γ_n to the single-particle width is exceptionally small, and it may be that this state has $T=\frac{3}{2}$ and is therefore the analog of a low-energy state in C^{15}.

The interference between the 1.31- and 1.50-Mev resonances is unusual in that it appears in the total cross section. This can only occur between states of the same spin and parity. Between two such interfering states of $J=0$ or $\frac{1}{2}$, terms higher than P_0 do not occur. A more detailed report of this work is being submitted to the *Canadian Journal of Physics.*

[1] These reactions have been studied by a large number of authors. See F. Ajzenberg and T. Lauritsen, Revs. Modern Phys. **34**, 321 (1952).
[2] Spearman, Hudspeth, and Morgan, Phys. Rev. **94**, 806 (1954) and I. L. Morgan (private communication).
[3] Roseborough, McCue, Preston, and Goodman, Phys. Rev. **83**, 1133 (1951).
[4] Kay, Mark, and Goodman, Phys. Rev. **91**, 472 (1953).
[5] Hinchey, Stelson, and Preston, Phys. Rev. **86**, 483 (1952).
[6] C. H. Johnson and H. H. Barschall, Phys. Rev. **80**, 818 (1950).
[7] A. M. Lane, Atomic Energy Research Establishment, Harwell Report T/R 1289, 1954 (unpublished).
[8] V. F. Weisskopf, Phys. Rev. **83**, 1073 (1951); S. A. Moszkowski, Phys. Rev. **83**, 1071 (1951).
[9] This has been pointed out by V. L. Telegdi and by W. E. Burcham (private communications).
[10] D. C. Peaslee, Phys. Rev. **95**, 717 (1954).

Direct Interaction in $Fe^{56}(p,p')Fe^{56*}$†

G. SCHRANK, P. C. GUGELOT, AND I. E. DAYTON
Palmer Physical Laboratory, Princeton University, Princeton, New Jersey
(Received September 28, 1954)

INVESTIGATIONS on the energy spectra of inelastically scattered nucleons[1–3] and measurements on the yield of nuclear reactions[4] have recently case some doubt on the applicability of the statistical theory of nuclear reactions. Austern, Butler, and McManus,[5] in order to explain the large observed (n,p) and (n,α) cross sections, proposed a new mechanism which describes the reaction as a consequence of an interaction between the incoming particle and one of the nucleons at the surface of the nucleus in place of an interaction between the bombarding particle and the whole nucleus. This theory, which is analogous to Butler's deuteron stripping calculations, predicts the differential cross section for a reaction in which the residual nucleus is left in an excited state. The angular distribution of the emitted particles is a function of the angular momentum and parity change between the initial and final states.

To test this hypothesis we investigated the angular distribution of protons inelastically scattered from iron. The experimental apparatus was the same as described by Dayton and Schrank.[6] Figure 1 presents the observed absolute differential cross sections for the inelastic scattering of 17-Mev protons (c.m. energy) to the 0.822-Mev level[7] of Fe^{56}. Some care had to be taken at small scattering angles in the separation of the inelastic and elastic scattering. The errors include the uncertainty in the correction which was necessary to account for the spilling over of elastically scattered protons into the inelastic channels. For this reason the point at 25° is to be regarded as an upper limit to the actual value there. The elastic scattering cross section at this angle is 767 mb/sterad.

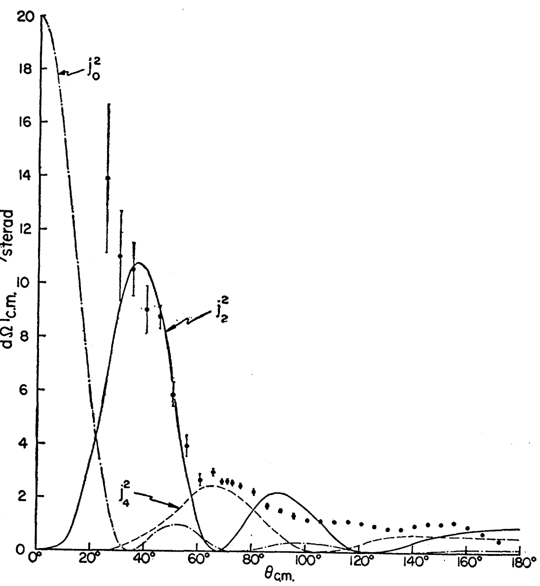

FIG. 1. Scattering of 17-Mev protons to the 822-kev level of Fe^{56}. The curves shown are the squares of the spherical Bessel functions of zeroth, second, and fourth order obtained from the work of Austern, Butler, and McManus.

In this case, where the initial state has zero spin and the final state is presumably a 2^+ level, the differential cross section will be proportional to $[j_2(QR)]^2$ according to the direct interaction picture, where $Q=|\mathbf{k}_{in}-\mathbf{k}_{out}|$, k is the wave number of the incoming or outgoing particle respectively, and R is the nuclear radius ($1.5\times10^{-13}A^{\frac{1}{3}}$ cm). Curves are shown for $[j_0(QR)]^2$, $[j_2(QR)]^2$, and $[j_4(QR)]^2$. The normalization is arbitrary for each curve. The figure shows that the main forward peak of the experimental cross section may be approximated by the spherical Bessel function of second order as predicted by the theory of Austern *et al.* Also, as predicted, the first-order and the third-order functions do not agree with the observed angular distribution since these functions of odd order prescribe a parity change between initial and final states.

These results show that this low-lying state is excited by a process different than that of the decay of a compound nucleus, since the angular distribution predicted by Hauser and Feshbach[8] on the basis of the statistical theory should be symmetric around 90°, and a rough calculation showed that the distribution is