Elastically Scattered Protons from Carbon*

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The excited states of N^{13} were investigated by use of the $C^{12}(p,p)$ reaction. Only the two resonances, at 465-kev and 1.7-Mev proton energies, previously known from the $C^{12}(p,\gamma)N^{13}$ reaction were found. The energy region covered was from 0.3- to 4.0-Mev proton bombarding energy. The elastically scattered protons were observed by the use of a 90° magnetic analyzer at an angle of 164° to the incident beam. The intensities at the resonances show that the 465-kev level has $J=\frac{1}{2}$ and that the 1.7-Mev level has probably $J=3/2$ or $5/2$.

I. INTRODUCTION

THE recent determination of the two lowest resonances in gamma-ray yield for the $C^{12}(p,\gamma)$ reaction (at proton energies of[1] 465 kev and[2] 1.7 Mev) led to an apparently poor correspondence of levels in N^{13} and its mirror nucleus C^{13}. The two N^{13} levels under consideration here are at $\sim$2.4 and 3.5 Mev, and the two corresponding levels[3] in C^{13} are at $\sim$3.1 and 3.7 Mev. However, since our data were taken, theoretical work has been brought to our attention which makes these shifts plausible.[4,5] The present work was undertaken to check further the two known levels in N^{13} and to search for new levels. The data give the yield of protons scattered elastically from carbon at an angle of 164°; proton energies range from 0.3 to 4.0 Mev, corresponding to excitation energies of 2.2 to 5.7 Mev in the compound nucleus N^{13}.

II. APPARATUS

A magnetically separated proton beam from the Wisconsin electrostatic generator passes through the 90° electrostatic analyzer (Fig. 1) for energy measurement and definition. After passing through the exit slit of the electrostatic analyzer, the beam passes through two further slits of the 90° magnetic analyzer, described by Shoemaker, et al.,[6] which reduce the beam to a 2×2 mm square striking the target. This "illuminated" target spot is the "object" of the 90° magnetic analyzer which was here used to separate the elastically scattered protons from the various target elements. This analyzer was here, as in previous experiments,[6] set up to analyze the protons scattered at 164° to the incident beam, with an angular spread of $\pm5°$.

[1] W. A. Fowler and C. C. Lauritsen, Phys. Rev. **76**, 314 (1949).
[2] D. M. Van Patter, Phys. Rev. **76**, 1264 (1949).
[3] All energy levels quoted are taken from the recent compilation by Hornyak, Lauritsen, Morrison, and Fowler, Revs. Modern Phys. **22**, 291 (1950).
[4] J. B Ehrman, Phys. Rev. **81**, 412 (1951).
[5] R. G. Thomas, Phys. Rev. **80**, 136(A), 138(A) (1950); and private communication.
[6] Shoemaker, Faulkner, Bouricius, Kaufmann, and Mooring (to be published).

In the present investigation, the flip coil and fluxmeter that had previously been used was replaced by a more accurate and less tedious magnetic flux balance, similar to that described by Buechner, et al.[7] It was, thus, possible to reproduce magnetic field measurements to an accuracy of better than 0.1 percent.

A scintillation counter, consisting of a 1P21 photomultiplier tube with a zinc sulfide screen dusted on, was used for counting the scattered protons. This was placed at the "image" position of the 90° magnetic analyzer and was used for the entire yield curve. In the absolute cross section determination (Sec. IV), a proportional counter with a 0.00005-inch nickel window was used.

III. THE YIELD CURVE

(A) Procedure

The targets used for the yield curve were thin soot deposits on 1000A nickel backings.[8] The targets were prepared by holding the nickel foils on nickel frames in the smoke of burning camphor. The targets were then mounted in position for bombardment while still in the nickel frames. An approximate target thickness determination was made by measuring the energy loss of protons scattered by the nickel backing on two tra-
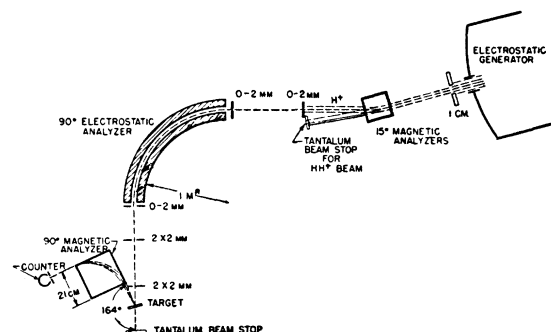

FIG. 1. Proton beam collimating slits and analyzers.

[7] Buechner, Strait, Sperduto, and Malm, Phys. Rev. **76**, 1543 (1949).
[8] Nickel foils are obtained on copper backings from the Chromium Corporation of America, 100 East 42nd St., New York 17, N. Y. For handling, see article by S. Bashkin and G. Goldhaber, Rev. Sci. Instr. **22**, 112 (1951).
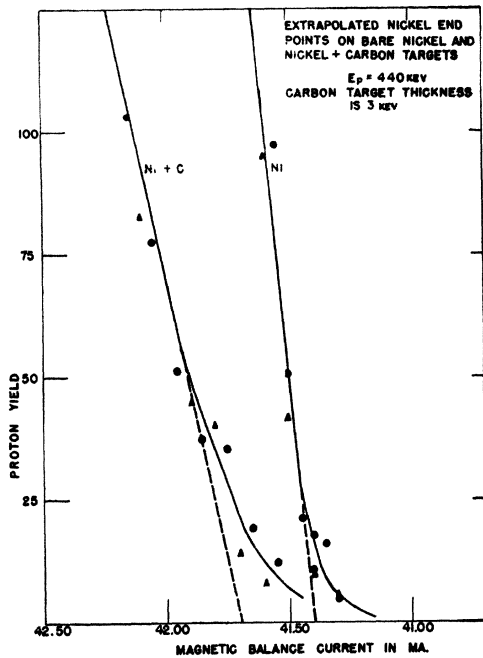
Fig. 2. High energy edges of proton groups scattered from nickel. Different symbols refer to different runs.

versals through the carbon layer. The sharp rise of the yield of elastically scattered protons from nickel at the high energy side of the peak (nickel end point) was measured as a function of magnetic field settings. The shift between the extrapolations of two such nickel end-point curves (Fig. 2), one for a bare nickel target and one for a carbon on nickel target, corresponds to the energy loss for two traversals of the carbon. It is estimated from the comparison with weighed targets (Sec. IV) that this method is probably good within ±30 percent. Some of the nickel end-point curves for carbon on nickel targets varied in slope, and we believe that this is attributable to carbon target inhomogeneity and straggling. It is possible that the shift half-way up
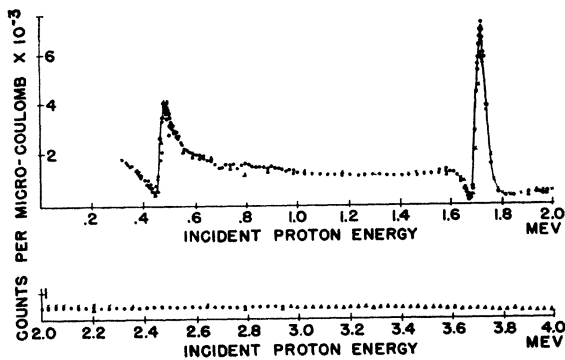

Fig. 3. Yield curve of elastically scattered protons from carbon at 164°, uncorrected for scintillation counter efficiency. 765 counts/μcoulomb corresponds to 10^{-25} cm^2/steradian. Rutherford scattering amounts to 3900 counts/μcoulomb at 0.3 Mev and just passes through the minimum of the 1.7-Mev resonance. Different symbols refer to different targets used.

the curve would give a better average target thickness estimation than does the extrapolated shift. Further investigations with evaporated targets would be necessary to establish this as a quantitative method. The targets used ranged in thickness from 1 kev to 3 kev at 500-kev bombarding energy.

At each point of the yield curve (Fig. 3), partial $H\rho$ curves were taken over the top of the elastically scattered proton yield from carbon. (Figure 4 shows a typical complete $H\rho$ curve.) The points of the $H\rho$ curve were taken by the use of a current integrator[9] which stopped the scaler after a predetermined charge was collected. The peak value of each partial $H\rho$ curve was used as the value shown in the yield curve for that
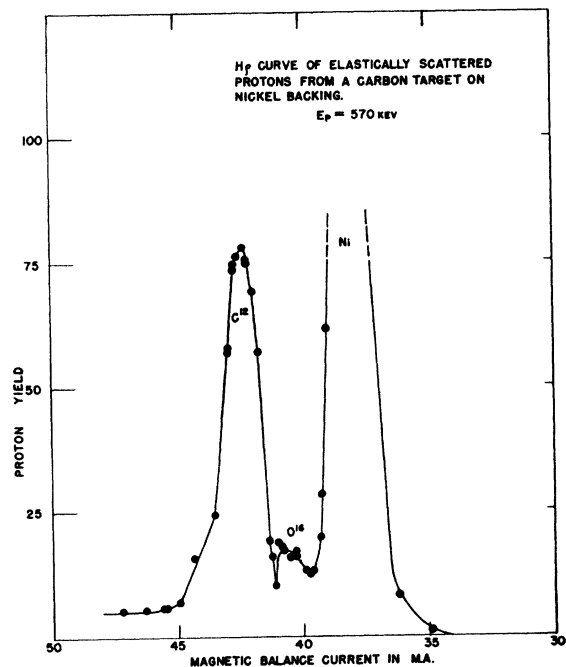

Fig. 4. Proton groups scattered from carbon, nickel, and oxygen.

bombarding energy. The detector window was always wider than the energy spread of particles from the thin target. Thus, the yield was always proportional to the number of target atoms.

For the general survey of the region from 0.3 to 4 Mev, points were taken 30 kev apart with a resolution of 0.2 percent. In the region of the two resonances found, points were taken with a much closer spacing. Below 1-Mev bombarding energy the diatomic beam (HH^+) was used, while above that energy the proton beam (H^+) was used. Below 400 kev the elastically scattered protons from nickel and carbon could no longer be clearly separated. The data below that energy was taken by reversing the target. This placed the carbon layer behind the nickel foil and, thus, again gave a clear separation on the $H\rho$ plot. The effective

[9] G. M. B. Bouricius and F. C. Shoemaker, Rev. Sci. Instr. 22, 183 (1951).

bombarding energy for these points was determined by remeasuring the points at the minimum of the 456-kev resonance with the target reversed, and then realigning the two energy scales at this minimum yield point. This gave a 15-kev energy loss due to the passage through the 1000A (nominal thickness) nickel foil at 440-kev proton energy.

(B) Results

In the region covered by the yield curve (0.3- to 4-Mev bombarding energy), only two resonances were found. These are the[1] 456-kev and the[2] 1.7-Mev resonances, both previously observed for the $C^{12}(p,\gamma)N^{13}$ reaction (see Table I). The 1.7-Mev resonance has associated with it, aside from the pronounced minimum and maximum at 1.68 and 1.73 Mev, respectively, an additional small maximum at 1.61 Mev and a minimum at 1.83 Mev. These are believed to be real. There is a rather high "nonresonance yield" of 1.45×10^{-25} cm^2/steradian (considerably above Rutherford scattering) in between the two resonances which drops off sharply to 0.63×10^{-25} cm^2/steradian as the 1.7-Mev resonance is crossed. This nonresonance yield then continues out to 3 Mev at essentially the same cross-section value. A further decrease in yield to 0.34×10^{-25} cm^2/steradian is then observed around 3.5 Mev. Cross checks between the proportional counter, used for the absolute cross section determination (Sec. IV), and the scintillation counter, used for the yield curve at 1.3 and 2.7 Mev, seem to indicate that the scintillation counter efficiency decreases at the higher bombarding energies by about 10 to 20 percent. A similar cross check at the low bombarding energies (around the 456-kev resonance) was not possible, as the proportional counter window did not allow a reliable counting of protons of less than 500-kev energy. Visual observation of pulse-height distribution suggests, however, some loss of counting efficiency below 500 kev causing the yield curve to be low in this region.

No evidence was found for any other resonances of width and intensity comparable to the two resonances observed. However, recent work at this laboratory[10] on elastically scattered protons from O^{16} showed a very narrow level (width about 3 kev) in F^{17}. It is conceivable that similar levels in N^{13} could have been missed in the present survey. Some small wiggles in the yield curve between 0.5 and 1.0 Mev could arise from the natural C^{13} abundance in the carbon target, as the analyzer could not resolve elastically scattered protons from C^{12} and C^{13}.

IV. ABSOLUTE CROSS SECTION

Two types of weighed targets were used in ascertaining an absolute value for the differential cross section. Three soot targets, having weights of 40, 130, and 330 μg/cm^2, were deposited on nickel foils. Two

[10] Laubenstein, Laubenstein, Mobley, and Koester, Phys. Rev. 81, 654 (A) (1951).

TABLE I. Data on the two observed resonances.

Resonance (Mev)	E_{min} (Mev)	E_{max} (Mev)	ΔE^a (kev)	σ_{min} (10^{-25} cm^2/steradian)	σ_{max}
0.456	0.441	0.485	44	0.62[b]	5.3[b]
1.7	1.68	1.73	50	0.12	9.3

[a] $\Delta E = E_{max} - E_{min}$.
[b] These values may be too small because of a possible loss of scintillation counter efficiency.

Formvar foils, weighing 110 and 300 μg/cm^2, were also used. A microchemical analysis[11] of the Formvar "E" used gave 56.7 percent carbon and 8.1 percent hydrogen, the remainder being oxygen plus small impurities. The weighing techniques were estimated to be accurate to ± 3 μg. The target areas, about 1 cm^2, were known to ± 10 percent. The uniformity of both types of targets and the stability under bombardment are estimated to be good to ± 20 percent.

The magnetic analyzer, equipped with a proportional counter, was used as described in Sec. II. Fluctuations in yield of ± 10 percent arose as the proton beam shifted in the slits which define the target spot and are probably attributable to target inhomogeneity. Net yields from the five targets at 1.3 Mev give cross sections of 1.60, 1.71, 1.39, 1.46, 1.37×10^{-25} cm^2/steradian. The unweighted average is $1.5 \pm 0.14 \times 10^{-25}$ cm^2/steradian. Considering the previously discussed possible systematic errors, the total estimated error is ± 25 percent. 765 counts/μcoulomb (Fig. 3), thus, corresponds to 10^{-25} cm^2/steradian.

V. DISCUSSION

The over-all yield curve shows only the two resonances previously reported[1,2] from the $C^{12}(p,\gamma)$ reaction. No other resonances were found in the region of observation, although this region overlapped that in the mirror nucleus C^{13} in which an uncertain level at 5.7 Mev has been reported.[3] Quantitative comparison of the values E_r and Γ with those derived from the proton capture data awaits a detailed theoretical fit of the scattering data.

If $(\sigma_{max})^{\frac{1}{2}} - (\sigma_{min})^{\frac{1}{2}}$ at a resonance is large compared to $(\sigma_{min})^{\frac{1}{2}}$ and if $\sin^2\theta$ is small compared to unity, the following formula is valid for spin $\frac{1}{2}$ particles scattered

TABLE II. Calculated resonance scattering amplitudes.

	$(\sigma_{max})^{\frac{1}{2}} - (\sigma_{min})^{\frac{1}{2}}$
Resonance	465 kev	1.7 Mev
Experimental	0.48×10^{-12} cm	0.85×10^{-12} cm
Calculated $^2S_{\frac{1}{2}}$	0.70	0.37
$^2P_{\frac{1}{2}}$	0.67	0.36
$^2P_{\frac{3}{2}}$	1.3	0.71
$^2D_{\frac{3}{2}}$	1.2	0.67
$^2D_{\frac{5}{2}}$	1.8	1.0

[11] We are indebted to Dr. A. L. Wilds of the Wisconsin Organic Chemistry Department for this analysis.

by a spin zero nucleus.[12,13]

$$(\sigma_{max})^{\frac{1}{2}} - (\sigma_{min})^{\frac{1}{2}} = (J+\tfrac{1}{2})\lambda P_L(\cos\theta).$$

Table II shows that the 465-kev level is best assigned $J=\frac{1}{2}$. Some loss in scintillation counter efficiency would account for the smaller experimental intensity. Since only the assumption of $L=0$ gives a level "width without barrier" of reasonable value,[14] the level is probably $^2S_{\frac{1}{2}}$. Further, the gamma-radiation intensity from the corresponding level in C^{13} to its ground state, presumed to be $^2P_{\frac{1}{2}}$, appears to be electric dipole radiation.[5] The data for the 1.7-Mev level[15] show an intensity midway between $J=3/2$ and $J=5/2$. However, the small concomitant maximum at 1.61 Mev and minimum at 1.83 Mev may be the result of a second level in this neighborhood, and the single level intensity analysis may not be valid.§

[12] C. L. Critchfield and D. C. Dodder, Phys. Rev. **76**, 602 (1949).

[13] This extension of the formulas in reference 12 is due to R. A. Laubenstein.

[14] Fowler, Lauritsen, and Lauritsen, Revs. Modern Phys. **20**, 236 (1948).

[15] From comparison of the calculated level shift between the levels in N^{13} (3.5 Mev) and C^{13} (3.7 Mev) with the experimental value, R. G. Thomas concludes that a p wave should be assigned here (private communication).

§ *Note added in proof.*—Preliminary results of an analysis by H. L. Jackson and A. I. Galonsky (to be published) show that a

It is apparent that a more reliable absolute cross section would be of value in the assignment of level configurations. The cross-section measurement could be improved by extending the present data below 300 kev into a region of pure Rutherford scattering. Another possibility is the use of a methane gas target and a proportional counter for both absolute cross section and angular distribution measurements. Angular distributions, taken at the two resonances, would help further in assignment of angular momenta.[16]

We wish to thank Professor H. T. Richards for suggesting this problem to us and for many helpful discussions. We are also indebted to R. A. Laubenstein, H. L. Jackson, and M. J. W. Laubenstein for aid in taking data.

P (1.68-Mev) level and a $D_{\frac{5}{2}}$ (1.73-Mev) level of comparable widths account for the shape near resonance. For the corresponding level of the mirror nucleus C^{13}, J. Rotblat (Proc. of the Harwell Nuclear Physics Conference, 1950) reports finding a doublet in place of the 3.7-Mev level, from the $C^{12}(d,p)C^{13}$ reaction. He gives the values 3.77 and 3.90 Mev for the two components. See also a forthcoming paper by R. G. Thomas on this subject.

[16] W. D. Whitehead, Phys. Rev. **79**, 1022 (1950), has measured the angular distribution of elastically scattered protons from carbon for bombarding energies between 2 and 2.75 Mev. The data indicate the scattering of both s and p waves.

Radiations of UY

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The radiations of UY have been examined by absorption curve techniques. Among the radiations are: (1) 0.2-Mev beta, (2) L x-rays, (3) 35-kev gamma-ray, (4) soft electronic component, probably conversion electrons about 50 kev, (5) soft quantum component, probably M x-rays, and (6) two harder gamma-rays, 65 to 75 kev and about 100 kev. On abundance and coincidence considerations, a tentative decay scheme is suggested which includes a 0.2-Mev beta followed by 35- and 65-kev gamma-rays in cascade with a 100-kev cross-over transition. The half-life was found to be $25.6_4 \pm 0.1$ hours.

I. INTRODUCTION

IN the course of a cross-section measurement[1] on the reaction $Th^{230}(n,\gamma)Th^{231}$ by direct determination of the Th^{231} (or UY) disintegration rate, it was found necessary to have some information on the UY decay scheme. Such information was necessary in order to evaluate the fraction of the counts measured which were due to disintegration betas. Some preliminary work has been done on the decay scheme, by the use of absorption methods. The poor resolution of these methods enabled the determination of only the gross features of a decay scheme, which were, we believe, sufficient for the purposes of evaluating disintegration rates (with the aid of suitable corrections). Our results indicate that further work is necessary to determine the correct scheme.

As indicated above, UY can be made through the

[1] A. H. Jaffey and E. K. Hyde, Argonne National Laboratory Report ANL-4249, Febuary, 1949, unpublished.

absorption of neutrons by ionium, or it can be isolated from uranium samples, since it is the daughter of U^{235} decay ($U^{235} \xrightarrow{\alpha} Th^{231}$). Prior to World War II, the usual source of UY had been natural uranium. By separating the thorium fraction from a large amount of uranium, it is possible to get a reasonable amount of UY.

Unfortunately, UY so separated always has large amounts of $UX_1(Th^{234})$ and UX_2 present, even when short periods (one to two days) of growth are used in order to increase the relative concentration of the short-lived (25.6 hr) UY over that of the 24.1-day UX_1. Most measurements made on UY separated from natural uranium were made by difference. The UX_2 radiation was measured after the decay of the UY; and after correcting for the UX_1 decay, these measurements were subtracted from the measurement on the original $UX_2 + UY$ radiations.

Because of the difficulties in such measurements,