Inelastic Scattering of Protons from Light Nuclei

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A method has been developed for doing scattering experiments inside the vacuum chamber of an f-m cyclotron. The magnetic field of the cyclotron is used to analyze the scattered beam. The spectrum of the scattered particles is recorded on photographic plates, and lines corresponding to states of the scattering nucleus are found. Levels are reported for B, C^{12}, N^{14}, O^{16}, Mg, Al^{27}, and Ni.

I. INTRODUCTION

EXPERIMENTS which show that protons of energies up to 8 Mev can be scattered inelastically by certain nuclei have been made by a number of investigators.[1] The method has generally been to direct at the scatterer a collimated beam of approximately monoenergetic protons, then by means of range measurements or by use of an analyzer magnet to determine the energy distribution of the protons scattered through a known angle. The highest energy peak in the distribution curve corresponds to elastic scattering, and the lower energy peaks correspond to inelastic scattering. From the energy values of the peaks the positions of the corresponding nuclear energy levels can be calculated by use of the laws of conservation of energy and momentum. In this way portions of the energy level schemes of a number of naturally occurring isotopes have been obtained.

The experiments described below are of the same general sort, but are different in several respects: they are done inside the vacuum chamber of the cyclotron; no special equipment is required for collimating or analyzing the primary beam; the magnetic field of the cyclotron is used for analyzing the scattered beam; energies up to 17 Mev are used.

II. METHOD

The Princeton cyclotron is a 35-in. f-m machine with a single dee. The scattering camera (see Fig. 1 and Fig. 2) rests on the floor of the dee chamber, beneath the beam, in the region normally occupied by the second dee of a two-dee cyclotron. The scattering foil, which is both thin and narrow, is held vertical so that it intercepts the beam. Protons scattered slightly downward follow helical paths of small pitch. Some of them pass through the vertical slit and strike the horizontal photographic plate at a glancing angle of about 15°. Since the radius of the helix followed by a particular proton depends upon the momentum of that proton, a spectrum of the scattered beam is recorded on the plate. Ilford nuclear physics plates with 50-μ and 100-μ thick emulsions have been used so that the full range (up to about 1000μ) of most protons would be spent in the emulsion. Lines easily visible to the unaided eye, each corresponding to a state of the residual nucleus, are obtained with beam currents of half a microampere and exposure times of thirty minutes.

Figure 3 shows the spectrum obtained from platinum with a primary beam energy of 15 Mev. Only one proton line, the elastic line,[2] can be seen. The sharply defined line on the left lies in

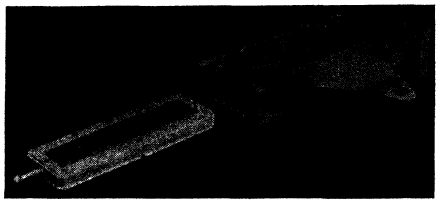


FIG. 1. Small scattering camera and plate holder. The plate is covered with a 0.5-mil aluminum foil. The body of the camera is made of dural and the slit jaws are of copper.

[1] T. R. Wilkins and G. Kuerti, Phys. Rev. **57**, 1082(A) (1940); T. R. Wilkins and G. Wrenshall, Phys. Rev. **58**, 758 (1940); T. R. Wilkins, Phys. Rev. **60**, 365 (1941); R. H. Dicke and J. Marshall, Jr., Phys. Rev. **63**, 86 (1943); J. Chadwick, A. N. May, T. G. Pickavance, and C. F. Powell, Proc. Roy. Soc. **183A**, 1 (1944); H. Heitler, A. N. May, and C. F. Powell, Proc. Roy. Soc. **190A**, 180 (1947); K. E. Davis and E. M. Hafner, Phys. Rev. **73**, 1242(A) (1948).

[2] For brevity the expressions "elastic line" and "inelastic line" will be used throughout for lines produced by elastic and inelastic scattering, respectively.

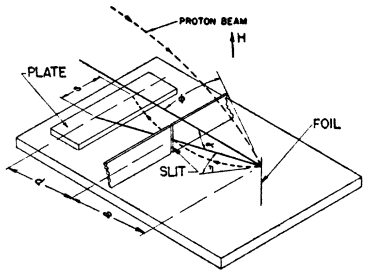


FIG. 2. Diagram of scattering arrangement. ($a \cong d \cong 5$ cm, s varies from 0.8 to 1.7 cm.)

a plane which passes through the slit and the scattering foil. Simple absorption measurements indicate that it is produced by soft, characteristic x-rays generated in the foil by the passage of the protons.[3] The x-ray line is a very useful reference mark in measuring the proton line deflections.

Calculations

The calculation of energies has been on a non-relativistic basis throughout. If the deviation, s, of a line has been measured the corresponding proton kinetic energy can be calculated from the equation

$$E=(e^2/2mc^2)H^2R^2(1+\mu^2), \tag{1}$$

where

$$R^2=\left(\frac{a\cos\alpha}{2}\right)^2+\left(\frac{s}{2}+\frac{d(a+d)\cos^2\alpha}{2s}\right)^2$$

and

$$\mu=\frac{(a+d)\sin\alpha}{R\sin^{-1}[2sd\cos\alpha/(s^2+d^2\cos^2\alpha)]}.$$

H is the vertical component of magnetic field (assumed constant); e and m are the charge and rest mass of the proton; and s, α, a, and d are defined in Fig. 2.

Equation (1) is based on the assumption of a helical path which originates at the intersection of the foil with the median plane of the beam. The position of the median plane was determined by probe measurements. Since the variation of H over the paths of the particles was less than 0.5 percent, the value of H at the slit was chosen as a reasonable average for use in the calculations.

[3] Such x-rays have previously been observed. M. S. Livingston, F. Genevese, and E. J. Konopinski, Phys. Rev. 51, 835 (1937).

A useful approximation, which under our conditions is always accurate to within 0.8 percent, is

$$E=(e^2/2mc^2)(H\cos\alpha)^2[d(a+d)/2]^2 \times[1/s^2+1/(a+d)^2+1/d^2]. \tag{2}$$

After the energies of the scattered proton groups have been calculated, the corresponding nuclear energy levels can be obtained by means of the laws of conservation of energy and momentum. The energy of the ith excited state is

$$E_{ei}=[(\beta-1)/\beta]E_0-[(\beta+1)/\beta]E_i +(2/\beta)(E_0E_i)^{\frac{1}{2}}\cos\theta, \tag{3}$$

where E_0 = energy of incident protons, E_i = energy of the ith group of inelastic protons, β = ratio of mass of scattering nucleus to proton mass, and θ = scattering angle. For the ground state, $E_{ei}=0$, and (3) may be solved for E_0 in terms of $E_i=E_{el}$, the energy of the elastically scattered protons:

$$E_0/E_{el}=1+2/(\beta-1)^2 \times[\beta-\sin^2\theta-\cos\theta(\beta^2-\sin^2\theta)^{\frac{1}{2}}]. \tag{4}$$

It is an important advantage of this method that E_0 can be chosen from a continuous range of values (extending in our case from 5 to 17 Mev) by setting the position of the camera so that the foil intercepts the beam at an appropriate radius. Furthermore, the scattering angle can be set to have any value between 20° and 160°.

A special camera which has eight slits and eight photographic plates arranged around a common scattering foil was often used.

It can be seen from Fig. 2 that the scattering angle θ has three parts. The part η, between the tangent to the scattered beam and the line between the foil, slit, and plate, varies slightly from line to line, but ϕ is constant, set by means of a jig which holds the camera. α is fixed by the geometry of the camera and the height of the beam. The beam is assumed to be centered horizontally at the geometrical center of the cyclotron.

Limits of accuracy

From (2) it follows that if there are errors δH, δa, and δs in the measurements of H, a, and s, respectively, the largest expected fractional un-

certainty in the calculated energy of a line is

$$\delta E/E = 2\delta H/H + 4\delta a/a + 2\delta s/s, \quad (a \cong d). \quad (5)$$

In our experiments the maximum expected errors in the measured quantities are all about one percent, so the maximum expected error in the absolute value of each energy is 8 percent. $\delta H/H$ and $\delta a/a$ are the same for all lines on a single plate, while $\delta s/s$ is different for each line. $\delta H/H$ is almost entirely systematic. The maximum errors expected in the energy levels calculated from the line energies obtained from a single plate are about 7 percent E_0. Most of the results quoted below represent averages over many separate determinations. The accuracy of the method can be improved by refining techniques, particularly by the reduction of δa by more accurate setting of the foil.

The widths of the lines arise principally from foil and slit width, spread in energy of the incident beam, foil thickness, vertical extension of the incident beam, and scattering from the slit edges. The total width corresponds to about 0.3 Mev. An analysis of the widths of the elastic lines obtained with $E_0 = 6$, 9, and 15 Mev shows that the spread in energy at "half-maximum" for the incident beam is less than 0.1 Mev in each case, and that the foil and slit widths are mainly responsible for the observed line width.

Preparation of foils

All the metallic foils used were about 6 mils wide and between 1.0 and 0.1 mil thick. They were cut by means of a special tool consisting of two razor blades clamped together with an appropriate spacer. By this procedure, foils of magnesium, aluminum, iron, nickel, copper, and platinum were made. It was found that lampblack, amorphous boron, several oxides, and a number of other chemical compounds would adhere to platinum if applied in a water or alcohol paste. In this way boron, carbon, nitrogen, oxygen, and fluorine scatterers were made. A quartz fiber was used for the examination of silicon and oxygen.

The foils were cemented to "C" shaped holders which were clamped in the scattering camera, as shown in Fig. 1. An aluminum baffle plate (not shown) was provided to prevent primary protons which got past the foil from striking the foil holder.

TABLE I. Summary of energy levels found in B, C^{12}, N^{14}, O^{16}, Al^{27}, Si^{28}, and Ni.

Element	Incident energies E_0 (Mev)	Line intensity S=strong M=medium W=weak	Energy levels E_{ei} (Mev)	Previously observed levels* (Mev)
B**	9.2, 15.6	W	2.2±0.3	2.1
	15.6	S	4.8±0.4	4.4
	15.6	S	6.5±0.3	5.8
	15.6	W	7.8±0.4	—
C^{12}	12.3, 15.0	S	4.4±0.2	4.3
	12.3, 15.0	M	5.5±0.3	—
	15.0	W	9.7±0.6	9.5
N^{14}	15.1	M	5.1±0.4	5.4
	15.1	M	6.7±0.4	6.6(?)
O^{16}	15.3	S	5.8±0.3	6.1, 6.3
	15.3	S	6.7±0.3	6.7(?)
	15.3	W	8.6±0.4	—
	15.3	W	9.7±1.0	10.5
Al^{27}	6.1, 9.6	W	0.9±0.2	0.87
	9.6	W	2.9±0.2	2.70
Si^{28}	15.3	W	4.6±0.3	—
Ni	15.3	W	3.8±0.4	—

* All the levels recorded in this column except those of aluminum were found by experimental means other than the inelastic scattering of protons (Hornyak and Lauritsen, reference 7).

** The calculation of energy levels for boron was based upon the assumption that the scattering nucleus had mass eleven. If any of the levels is due to B^{10}, the energy reported here will be somewhat high.

III. DISCUSSION OF RESULTS

The results obtained thus far are of the limited accuracy and resolving power indicated above. Furthermore, the scattering materials have not been analyzed for purity, and for this reason some small uncertainty exists in the assignment of the lines observed. It is hoped that experiments with separated isotopes of boron, magnesium, etc., can be made later. A summary of the present results is given in Tables I and II.

Boron

Foils consisting of a thin layer of amorphous boron (81.6 percent B^{11}, 18.4 percent B^{10}) on

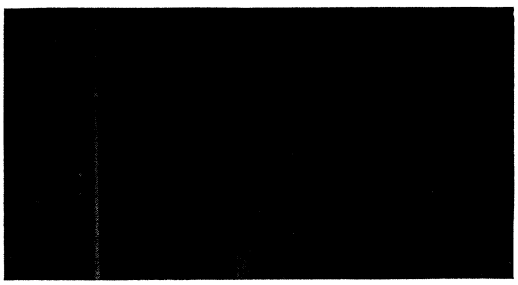


FIG. 3. Photograph taken with a platinum scattering foil at $E_0 = 15.0$ Mev and $\theta = 162°$. No inelastic lines are seen.

TABLE II. Summary of energy levels found in magnesium.

E_0(mean) (Mev)	R.M.S. deviation in E_0 (±Mev)	Line strength	E_{ex}(mean) (Mev)	R.M.S. deviation in E_{ex} (±Mev)	Number of observations	Estimated error (±Mev)
6.08	0.07	*M*	1.00	0.05	6	0.2
		M	1.58	0.03	6	0.2
9.64	0.20	*W**	0.59**	0.08	4	0.2
		S	1.33	0.06	10	0.2
		*W**	1.98	0.14	6	0.3
		*W**	2.64	0.02	3	0.3
		M	3.97	0.14	8	0.2
15.30	0.22	*S*	1.54	0.13	6	0.2
		S	4.17	0.05	8	0.2
		S	5.51	0.24	8	0.3
		M	7.32	0.30	7	0.3
		M	8.30***	0	2	0.4

* Observed only at $\theta=153°$ and 162°.
** Probably an elastic line due to oxygen contamination. See discussion under magnesium.
*** Observed only with small camera (Fig. 1).

platinum were prepared as described above. Exposures were made at $E_0=6$, 9, and 15 Mev with the single and multiple cameras. An example of the plates obtained is shown in Fig. 4a. Besides the elastic lines of platinum and boron, four other lines are found, the middle two being strong, the others weak. An examination of the plates under a microscope was made, and many short tracks presumed to be due to He^4 or He^3 nuclei were found. However, all the lines observed must have been caused by protons since they continued to appear when additional exposures were made with sufficient aluminum over the photographic plates to stop all the helium nuclei.

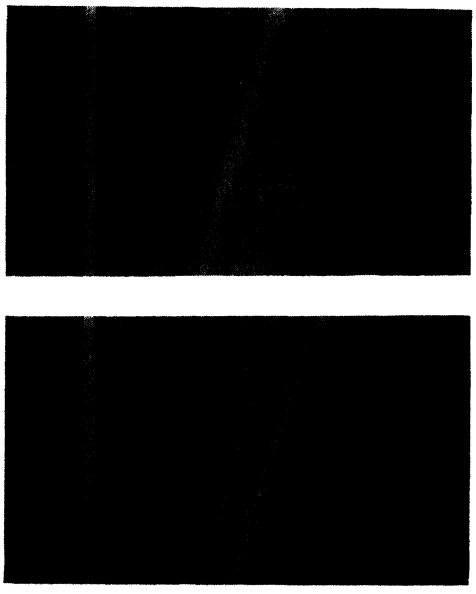


FIG. 4. (a) Photograph taken with boron on a platinum foil at $E_0=15.6$ Mev and $\theta=162°$. The vertical line on the far left is the x-ray line. The first slant line on the left is the platinum elastic line, and the next one is the boron elastic line. Beyond these are three inelastic lines, the first being quite weak. (b) Similar photograph taken with carbon on platinum foil at $E_0=15.3$ Mev and $\theta=162°$. Beyond the two elastic lines are two inelastic lines of carbon.

The intensity relationship of the various proton lines shows that the cross section for inelastic scattering from boron must be comparable with the cross section for elastic scattering. It is somewhat surprising that the (p,p) cross section is so large since the $B^{11}(p,\alpha)$ reaction is exothermic by 8.6 Mev, and the $B^{11}(p,n)$ reaction is endothermic by only 2.7 Mev. The threshold of the $B^{10}(p,n)$ reaction is 5.8 Mev.

Carbon

Foils were made by two methods: (a) a suspension of lampblack in ethyl alcohol was applied to a platinum foil, and (b) carbon was deposited on platinum by burning camphor. Three inelastic lines appeared when 12.3 and 15.0-Mev primary protons were used (see Fig. 4b). None of these appeared when the bombarding energy was 6 or 9 Mev. The corresponding energy levels are all assigned to C^{12} because of its 98.9 percent abundance.

Nitrogen

Foils of zirconium nitride on a platinum support were prepared by the method described in Section II. Multiple-angle exposures were made with incident energies of 6, 9, and 15.2 Mev. Inelastic lines were obtained only at 15.2 Mev. They were all attributed to scattering from nitrogen, chiefly because we have been unable to excite any well resolved levels in platinum, iron, copper, and nickel (except for a very weak line in nickel), while strongly excited levels have frequently been found in the lighter nuclei (see later discussion). The lowest level is calculated to lie at 5.1 ± 0.4 Mev, showing that we have not been able to find any evidence for an excited state in N^{14} below 4.7 Mev. This is interesting because of the prediction[4,5] that there should be

[4] E. Feenberg and E. Wigner, Phys. Rev. **51**, 95 (1937).
[5] R. Sherr, H. R. Muether, and M. G. White, Phys. Rev. (to be published).

an excited state of the N^{14} nucleus at about 2.4 Mev, having zero spin and corresponding to the ground state of C^{14}. The only definite experimental evidence that we know for such a level in N^{14} is the result of Sherr, Muether, and White,[5] which indicates that a gamma-ray of about 2.3 Mev is emitted by N^{14} as it decays to its ground state following the positron decay of O^{14}. Fowler, Lauritsen, and Lauritsen[6] reported a gamma-ray of 2.3 Mev from the $C^{13}(p,\gamma)$ process, but were unable to assign it to a transition between two particular states of N^{14}. The fact that the 2.3-Mev level is strongly excited in the positron decay process and only weakly at best by inelastic scattering makes further study of N^{14} desirable.

Oxygen and Silicon

Quartz fibers (SiO_2) of about 1.6-mils diameter were used in a number of exposures made with each scattering camera. Two elastic lines, two strong inelastic lines, and three weaker inelastic lines were found.

It was necessary to find a reason for assigning each line either to silicon or to oxygen. Three of the assignments were made by means of a test based upon the fact that the energy of a proton which has been scattered so as to leave the nucleus in a particular state depends upon the scattering angle. The laws of conservation of energy and momentum lead to the approximation

$$E_i(\theta)\cong E_i(\pi/2)+[2/(\beta+1)][E_i(\pi/2)E_0]^{\frac{1}{2}}\cos\theta,$$

which is good to within a few percent under our conditions. Thus experimental values of E_i plotted against $\cos\theta$ should give a straight line whose slope can be used to determine β. An example of the use of this method is illustrated in Fig. 5, where values of E_i for silicon and oxygen are shown plotted against $\cos\theta$. The scatter in points is considerable, but the method has indicated with a fair degree of certainty that oxygen should be assigned levels at 5.8 ± 0.3, 6.7 ± 0.3, and 8.6 ± 0.4 Mev, the first two of which have also been obtained with lead oxide scatterers. The method failed to give clear evidence for the assignment of the other two lines. Tentatively, a level at 9.7 Mev was assigned to oxygen and a level at 4.6 ± 0.3 Mev was assigned to silicon. The latter assignment

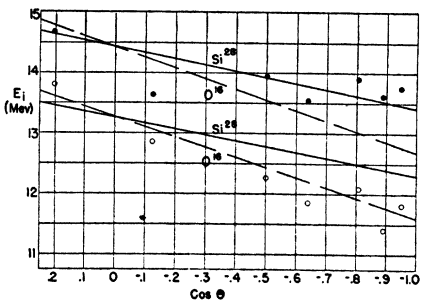


FIG. 5. Plot of energy of the two elastic groups of protons scattered from quartz (SiO_2) *vs.* the cosine of the scattering angle.

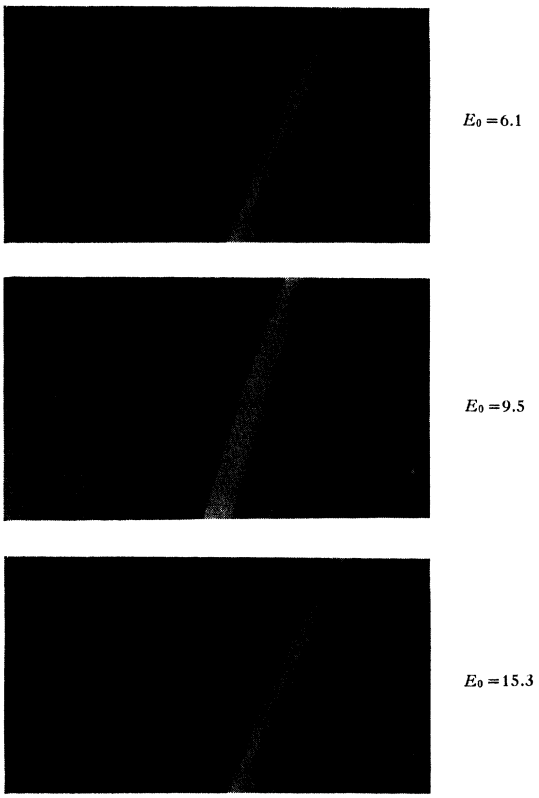


FIG. 6. Photographs taken with a magnesium scattering foil, at $\theta=162°$, and at the incident proton energies indicated in Mev at the right of each photograph. In the upper plate can be seen, from left to right, the elastic line and two inelastic lines. In the center picture are two inelastic lines barely resolved (these were clearly resolved in some of the plates), and another inelastic line on the far right. In the lower plate three additional lines may be seen. (In a number of the plates a line corresponding to $E_{ex}=1.54$ Mev was clearly resolved from the elastic line.)

[6] W. A. Fowler, C. C. Lauritsen, and T. Lauritsen, Rev. Mod. Phys. **20**, 236 (1948).

was based partly upon the fact that there are no known levels in O^{16} below 6.1 Mev.[7] Because of their high relative abundance, Si^{28} (94 percent) and O^{16} (99.8 percent) were assumed to be responsible for the inelastic scattering observed. Si^{28} is known from gamma-ray measurements[8] to have a level at 1.8 Mev, but we see no evidence for such a level on our plates.

Magnesium

The foils were made of commercial magnesium ribbon rolled to thicknesses ranging from 0.5 to 1.0 mil. Before being used they were washed in benzene and acetone.

Some of the pictures obtained are shown in Fig. 6. A summary of the results of all the magnesium pictures is given in Table II. With $E_0=6.1$ Mev two lines corresponding to energy levels at 1.00 and 1.58 Mev, respectively, were consistently found at all of the scattering angles used (78° to 162°). With $E_0=9.6$ Mev a different pattern was obtained with one strong line, corresponding to a level at 1.33 Mev, flanked by quite weak ones suggesting levels at 0.59 and 1.98 Mev. The line corresponding to the 0.59-Mev level is thought to be an elastic line resulting from oxygen impurity in the foil because (a) it occurs at the proper energy and (b) it appears much stronger in pictures made with foils which had been aged in air for several weeks. With $E_0=15.3$ Mev a single low lying level is found at 1.54 Mev. This may be the same as that found at 1.33 Mev with $E_0=9.6$ Mev. Unfortunately, the present energy values are too inaccurate to settle this point.

Because of the uncertainties in energy values (± 0.2 Mev), described in Section II, one cannot rule out the possibility that the calculated levels at 1.00 and at 1.33 Mev are identical, or that the levels reported at 1.58 and 1.98 Mev are identical.

A study of the variation of line energies with scattering angle was made as described in the section under oxygen and silicon. Although the measurements were too inaccurate for this test to be decisive, the evidence supports the belief that none of the stronger lines observed was the result of scattering from oxygen, nitrogen, or carbon. Examination of the plate under a microscope showed that none of the lines observed was composed of alpha-particle tracks. The other energetically possible reaction which might have caused complications is the (p,d) process. The threshold for the reaction $Mg^{24}(p,d)Mg^{23}$ is 13.3 Mev, so this reaction should not be of consequence here. The threshold for the reaction $Mg^{25}(p,d)Mg^{24}$ is 4.9 Mev, but the particular group of deuterons from this reaction which would leave Mg^{24} in its ground state would have appeared between the x-ray line and the elastic (p,p) line. Very few tracks of any sort appeared there. The threshold for the reaction $Mg^{26}(p,d)Mg^{25}$ is 9.8 Mev, so this reaction also is unimportant except possibly at the highest energy used. These arguments, along with the fact that the abundance of Mg^{25} and Mg^{26} is small (about 11 percent each), make it seem unlikely that any of the lines reported was due to a (p,d) reaction.

A definite assignment of the various levels to particular isotopes of magnesium on the basis of present results cannot be made, but there are several reasons to suspect that all the levels except possibly the weak ones at 2.0 and 2.6 Mev are due to Mg^{24}. First, the inelastic lines are about as strong as the elastic line. Second, the competing reaction $Mg^{24}(p,n)Al^{24}$ probably has a high threshold since Al^{24} has never been observed, while the reactions $Mg^{25}(p,n)Al^{25}$ and $Mg^{26}(p,n)Al^{26}$ have 4.7- and 3.6-Mev thresholds, respectively, and would be expected to compete strongly with the corresponding (p,p) reactions.

Dicke and Marshall,[1] using 6.9-Mev protons and a scattering angle of 135°, found a strongly excited level at 1.32 and weakly excited levels at 2.74 and 3.88 Mev. Wilkins' values are 1.37, 2.80, and 4.07 Mev. These probably correspond to our levels at 1.33 (and possibly 1.54), 2.64, and 4.17 Mev. It is known that gamma-rays of energies 2.76 and 1.38 Mev are consecutively emitted by Mg^{24} following the beta-decay of Na^{24},[9] so there must be a level at 4.14 Mev and another at either 2.76 or 1.38 Mev. Our level at 4.17 probably is the same as the 4.14-gamma-level, and it is possible that our 1.33 (and possibly 1.54) level is the same as the 1.38-gamma-

[7] W. F. Hornyak and T. Lauritsen, Rev. Mod. Phys. **20**, 191 (1948).
[8] E. Bleuler and W. Zünti, Helv. Phys. Acta **20**, 195 (1947).
[9] K. Siegbahn, Phys. Rev. **70**, 127 (1946).

level, but the large uncertainty in our energy values makes the comparison difficult. It has not always been possible to excite by inelastic scattering, levels known from gamma-ray spectroscopy (cf. discussion under silicon, nitrogen, and iron). There is evidence for a 1.3-Mev level found in experiments on the inelastic scattering of 2.5-Mev neutrons,[10] but the results are not good enough statistically to eliminate the possibility that two levels might be found by that method.

Although quantitative data on the intensities of the various lines have not been obtained, it is clear from visual inspection of the plates that with fixed E_0 the intensities of most of the strong lines remain roughly constant with angle. However, the neighboring lines corresponding to levels at 4.17 and 5.51 Mev show a relative variation which is clearly evident. For $E_0=15.3$ Mev and $\theta=90°$ their intensities are about equal, while at $\theta=162°$ that corresponding to 4.17 Mev of excitation is more intense, and at $\theta=78°$ the intensities are just reversed.

Aluminum

Two lines were found in the Al^{27} spectrum corresponding to levels at 0.9 ± 0.2 and 2.9 ± 0.2 Mev in good agreement with the results of Davis and Hafner[11] and Dicke and Marshall.[1]

Iron, Nickel, Copper, and Fluorine

When foils of iron, nickel, and copper were examined with $E_0=9$ and 15 Mev, a broad band of proton tracks appeared in each case. Figure 7 shows a typical picture obtained with iron. The proton band may be due to inelastic scattering, giving a number of unresolved overlapping lines, or it may be due to a three-particle disintegration of the compound nucleus, or to both. In the case of copper it is likely that some of the protons were from the $Cu^{63}(p,pn)Cu^{62}$ reaction, because the yield from this process was found to be large when 16-Mev protons were used to bombard a thick target.[12] The high energy edge of the proton band of copper corresponds to a first excited level at about 1.7 Mev. Values of 6.6 and 5.8 Mev were found for iron and nickel, respectively. In addition to the broad band, nickel pictures showed a very weak line corresponding to a level at 3.8 ± 0.4 Mev.

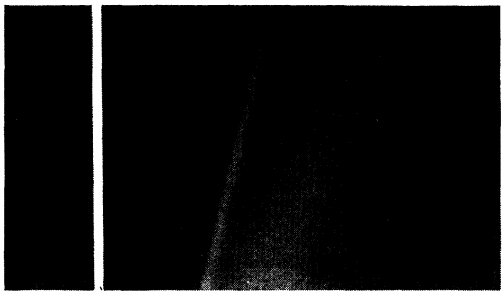


FIG. 7. Photograph taken with an iron scattering foil at $E_0=14.9$ Mev. and $\theta=162°$.

Sodium fluoride and strontium fluoride scatterers gave patterns similar to those obtained with iron, with a "threshold" of about 5.0 Mev. This figure is too low to apply to the (p,pn) process in either sodium or fluorine, because calculations based on the known masses of Na^{23}, Na^{22}, F^{19}, and F^{18} indicate Q values of about -12 and -10 Mev, respectively. The masses of the iron, nickel, and copper isotopes are not known well enough for similar calculations to be applied to their cases.

It is known from beta-ray spectrographic work that Fe^{56} (92 percent) has levels at 0.845, 2.65, and 2.98 Mev.[13] We find no evidence for them, but this is not surprising since the (p,n) threshold for Fe^{56} is 5.47 Mev,[13] while the Coulomb barrier is higher, about 6.8 Mev.

We wish to thank Professors M. G. White and R. Sherr, and H. R. Muether for permission to use their results on N^{14} before publication. We also wish to acknowledge the stimulating interest of members of this laboratory and the assistance of the cyclotron staff.

This work was assisted by the joint program of the office of naval research and the atomic energy commission.

[10] R. N. Little, R. W. Long, and C. E. Mandeville, Phys. Rev. **69**, 414 (1946).

[11] K. E. Davis and E. M. Hafner, paper presented at the New York meeting of the American Physical Society, January 1948.

[12] A two-minute bombardment produced a strong 10.5-minute copper activity presumed to be due to Cu^{62}. Roughly speaking, the yields from the $Cu^{63}(p,pn)Cu^{62}$ and $Cu^{63}(p,n)Zn^{63}$ reactions were equal.

[13] L. G. Elliot and M. Deutsch, Phys. Rev. **64**, 321 (1943).

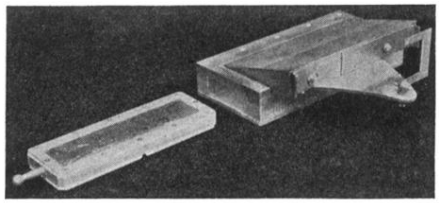


FIG. 1. Small scattering camera and plate holder. The plate is covered with a 0.5-mil aluminum foil. The body of the camera is made of dural and the slit jaws are of copper.

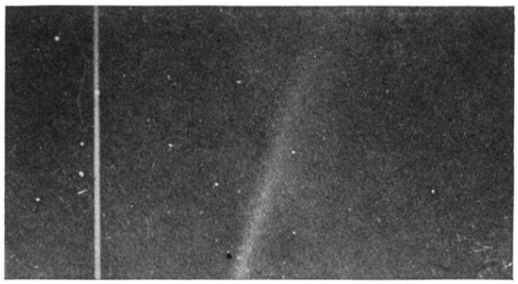
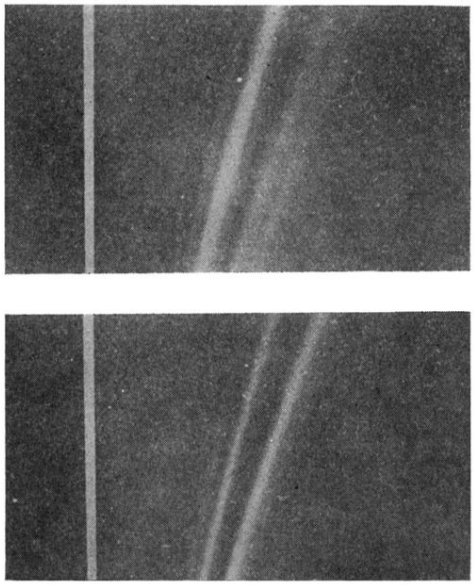


FIG. 3. Photograph taken with a platinum scattering foil at $E_0 = 15.0$ Mev and $\theta = 162°$. No inelastic lines are seen.



(a)

(b)

FIG. 4. (a) Photograph taken with boron on a platinum foil at $E_0=15.6$ Mev and $\theta=162°$. The vertical line on the far left is the x-ray line. The first slant line on the left is the platinum elastic line, and the next one is the boron elastic line. Beyond these are three inelastic lines, the first being quite weak. (b) Similar photograph taken with carbon on platinum foil at $E_0=15.3$ Mev and $\theta=162°$. Beyond the two elastic lines are two inelastic lines of carbon.

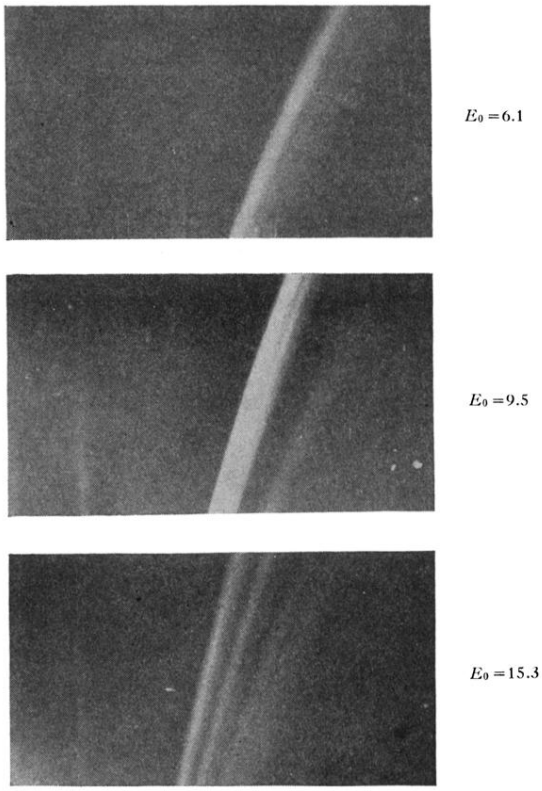


FIG. 6. Photographs taken with a magnesium scattering foil, at $\theta = 162°$, and at the incident proton energies indicated in Mev at the right of each photograph. In the upper plate can be seen, from left to right, the elastic line and two inelastic lines. In the center picture are two inelastic lines barely resolved (these were clearly resolved in some of the plates), and another inelastic line on the far right. In the lower plate three additional lines may be seen. (In a number of the plates a line corresponding to $E_{ei} = 1.54$ Mev was clearly resolved from the elastic line.)

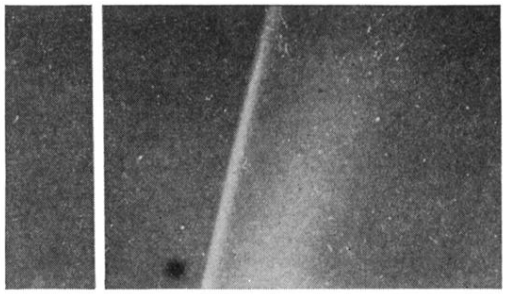


FIG. 7. Photograph taken with an iron scattering foil at $E_0 = 14.9$ Mev. and $\theta = 162°$.