Nuclear Energy Levels of Al^{27}†

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Twenty energy levels in Al^{27} have been found by the magnetic analysis of inelastically scattered protons at 90° from thin targets of aluminum. An analyzed beam of 8.0-Mev protons was utilized for the bombardment. Tentative values for the levels found are 0.844, 1.016, 2.259, 2.782, 3.046, 3.736, 4.018, 4.115, 4.473, 4.575, 4.647, 4.875, 4.996, 5.107, 5.220, 5.341, 5.501, 5.565, 5.620, 5.736 Mev. A broad alpha-particle group from the $Al^{27}(p,\alpha)Mg^{24}$ reaction corresponding to an excited state of Mg^{24} was also observed and is believed to be complex.

INTRODUCTION

WILKENS and Kuerti[1,2] were the first to report on the measurement of the energy levels of aluminum by observation of inelastic scattering of protons. Since then, additional studies of this same nucleus have been made by several observers both by inelastic scattering experiments[3–8] and by other nuclear reactions.[9,10] In the experiment to be described, a large magnetic spectrometer was utilized for the measurement of energy of charged particles emitted from an aluminum foil target bombarded with a beam of magnetically analyzed 8-Mev protons.

APPARATUS

Details of the apparatus have been published elsewhere.[11] The proton beam was produced by the 47-inch University of Pittsburgh cyclotron. A large focusing magnet, placed about seven feet from the cyclotron vacuum tank, focused the beam on the entrance slits of a beam analyzer magnet which was located in an adjacent room. An eight-foot thick shielding wall separated this room from the cyclotron chamber. After traversing the beam analyzer field the beam was limited by stops to an angular extent of ± 3 degrees horizontally and passed through a final analyzer slit, $\frac{1}{16}$ inch wide and $\frac{7}{8}$ inch high which limited the beam energy spread to 20 kev. Targets were placed at the center of a large scattering chamber at a distance of 1.75 inches from the final beam analyzer slit.

A large 60°-sector magnetic spectrometer was positioned at an angle of 90° with respect to the beam center. Charged particles emitted from the target were focused by this magnetic lens on a scintillation screen mounted external to the vacuum system. A 0.1-mil nickel foil served as the window. Stops were provided to limit the angular aperture to $\pm 2°$ with respect to the center line of the system.

Field excitation currents for the three magnets were obtained from motor-generator sets which were electronically stabilized. The magnetic field of the beam focusing magnet was adjusted so as to yield maximum beam on the entrance slit of the beam analyzer. The magnetic fields in the beam and particle analyzers were measured by means of the proton magnetic resonance method[12] to one part in 10,000 and were continuously monitored during the experiment. Target beam currents of 0.5 to 1.0 microamperes were obtained.

In order to provide uniform bombardments, an insulated Faraday cup was placed behind the target so as to collect the beam. This cup was connected to a precharged polystyrene condenser, the potential of which was monitored by means of a Lindeman-Ryerson electrometer. A switching arrangement was provided so as to permit termination of the counting period when the electrometer indicated zero potential.

Scintillation counters consisting of a phosphor screen and either an RCA type 5819 or an EMI 5311 photomultiplier tube were used as particle detectors. Rather thick layers of silver-activated zinc sulfide deposited on glass slides from alcohol-water suspensions were found to be satisfactory for initial survey work. These had adequate sensitivity for both alpha-particles and protons and yet were comparatively insensitive to the gamma-ray background. Thin deposits of this same phosphor were found to be useful in obtaining discrimination in counting alpha-particles in the presence of undesired protons. A selsyn-controlled absorption-foil shutter was mounted immediately in front of the scintillation screen so that alpha-particles could be stopped when desired. This shutter carried a number of aluminum foils of different thickness. Pulses from the photomultiplier tube were fed by a cathode follower through a long matched coaxial line to a separate room and further amplified by a Jordan and Bell type linear

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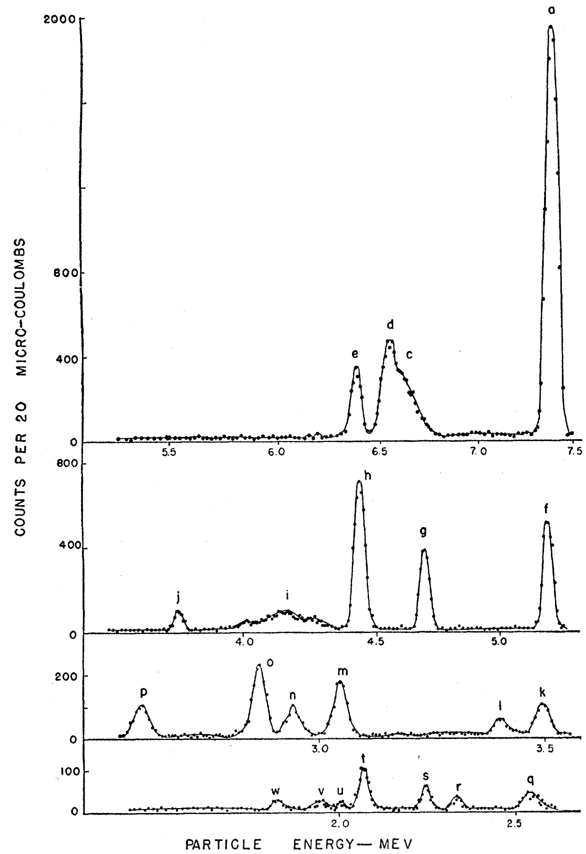

FIG. 1. Spectrum of magnetically analyzed particles obtained at 90° and Al^{27} bombarded by 8-Mev protons.

amplifier. The amplified pulses were fed into three pulse-height discriminators, each set at a different level and each connected to a separate scaling circuit. This counting arrangement permitted crude pulse-height analysis to be made and indicated whether protons, deuterons, or alpha-particles were being counted during initial searches for charged particle groups.

CALIBRATION

The spectrometer was calibrated by using alpha-particles from a polonium deposit on a nickel plate which was inserted in the normal target position. The $B\rho$ value assumed for these particles was 3.3159×10^5 gauss-cm[13] which corresponds to an energy of 5.298 ±0.002 Mev. Since the magnetic fields were always measured in terms of the frequency of proton magnetic resonance, the spectrometer constants were calculated in terms of frequency. The spectrometer constant[11] for alpha-particles (C_α) was found to be $(1.0363\pm0.002)\times10^{-14}$ Mev-sec^2, and the constant for protons (C_p) was found to be $(1.0292\pm0.002)\times10^{-14}$ Mev-sec^2. Group energies calculated from these constants and from the magnetic resonance frequencies corresponding to the centers of the groups were corrected for energy loss in the target and for relativistic shift.

RESULTS

A spectrum obtained from the bombardment of a 0.14 mg/cm^2 foil target is shown in Fig. 1. Spectroscopic analysis showed that there was less than 0.1 percent of Na, Cu, and Fe in the target. Twenty inelastic proton groups were observed, nineteen appearing in this particular run. Two alpha-particle groups from the $Al^{27}(p,\alpha)Mg^{24}$ reaction corresponding to excitation of the 1.38-Mev and 4.14-Mev levels in Mg^{24} were found. These two are labelled "*c*" and "*i*"§ in the figure. Carbon deposits which formed during bombardment contributed another proton group which does not appear in Fig. 1 since these data were obtained immediately after a clean target was inserted. The proton group "*d*" was superimposed on the alpha-group "*c*" and was isolated by insertion of a 10 mg/cm^2 absorbing foil between the spectrometer exit-slit and scintillation detector.

The energy resolution obtained for these groups was about one percent. The width of the groups was attributed to several sources: (1) the proton beam had a half-width of 20 kev; (2) the angular acceptance of the spectrometer plus the angular divergence of the beam contributed 45 kev to the width of 6 Mev; (3) the finite resolution of the spectrometer ($\frac{1}{16}$-in. source and exit slit widths) contributed 31 kev to the width at 6 Mev.

The measured line shapes were quite good fits to a normal distribution function and exhibited little asymmetry. Application of Pearson's chi-square test to the data for five of the most intense inelastic groups resulted in an average probability of 0.5 for the normal dis-

TABLE I. Energy levels of aluminum.

Present work	Alburger and Hafner	Keller	Shoemaker *et al.*	VanPatter
0.844	0.84		0.82	0.86
1.016	1.02	0.97	1.045	1.02
	1.85			
2.259	2.15	2.39	2.225	2.12
2.782	2.78		2.75	2.72
3.046	3.04	3.17		
3.736	3.7			
4.018				
4.115				
4.473	4.3			
4.575				
4.647		4.74		
4.875				
4.996				
5.107				
5.220				
5.341	5.3			
5.501				
5.565				
5.620				
5.736	5.8	5.76		

[13] VanPatter, Sperduto, Huang, Strait, and Buechner, Phys. Rev. **81**, 233 (1951).

§ *Note added in proof:* Subsequent investigations have shown peak "*i*" to be a doublet, corresponding to levels in Mg^{24} at 4.11 and 4.21 Mev.

tribution. Since a chi-square probability of 0.01 is considered satisfactory,[14] the lines were assumed to be normal in shape, and line centers were determined from the computed "best-fit" curves.

The energy levels determined for Al^{27} are shown in Table I and Fig. 2. The probable errors in these have been estimated as being 0.020 Mev from the uncertainty in determination of the group centers and from the uncertainty in the calibration constant. In Table I the levels listed by Alburger and Hafner,[15] which were the result of a literature survey covering the work reported before 1950, are given, along with more recent data reported by Keller,[8] by Van Patter, Sperduto, and Enge,[10] and by Shoemaker, Faulkner, Bouricius, Kaufmann, and Mooring.[16] It will be noted that in this experiment no scattering was observed corresponding to excitation of the 1.85-Mev level. Ten levels which were not previously reported were found.

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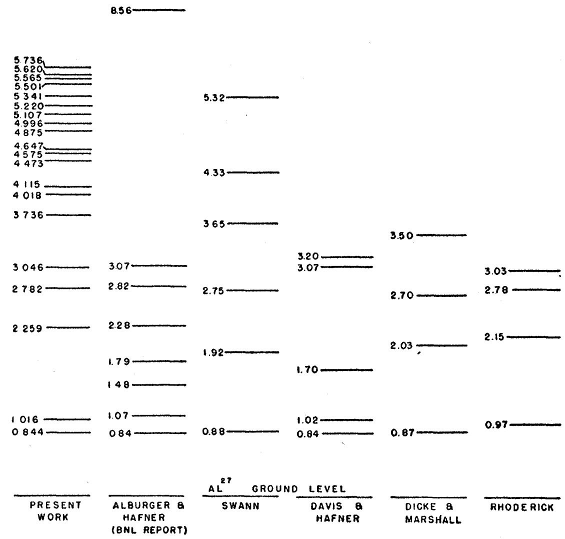

FIG. 2. Energy level scheme for Al^{27}.

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Inelastic Scattering of Protons from Nickel*

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By use of the equipment developed for the precision scattering project at the University of Pittsburgh, inelastic scattering of 8-Mev protons from a thin nickel target has been observed at 90°. The energy levels obtained for natural nickel are 1.344, 1.479, 2.186, 2.326, 2.501, 2.660, 2.814, 2.946, 3.081, 3.161, 3.226, 3.308, 3.462, 3.575,3 .646, 3.773, 3.823, 3.944, 3.979, and 4.066 Mev. At present, only the three levels 1.344, 1.479, 2.501 Mev can be assigned to nickel 60 from comparison with beta-decay of cobalt 60.

INTRODUCTION

ENERGY levels in nickel have been observed by the inelastic scattering of protons from a nickel foil. The apparatus and method of analysis of the data are the same as that of the preceding paper.[1] Dicke and Marshall,[2] with incident protons of 6.9 Mev, were unable to observe any levels in nickel. Fulbright and Bush,[3] using 5–17 Mev protons from the Princeton cyclotron, reported one weak level in nickel at 3.8 Mev as well as a broad band of tracks in the photographic emulsion used for detection. This broad band suggests either that a three-particle disintegration is occurring or that the levels are too close to be resolved with their equipment. In the present study, twenty energy levels have been observed.

The target (obtained from the Chromium Corporation of America) was a nickel foil of areal density 0.592±2.5 percent mg/cm². Spectroscopic analysis showed less than 0.01 percent of copper in the target. The source and analyzer slits were ⅛-inch wide. In all other respects the experimental details were essentially as reported in the preceding paper.

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