New Isotope, Al^{30}†

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Scintillation measurements were made of the beta and gamma radiation from high-purity natural silicon targets after bombardment with fast neutrons produced by the $Li^7(d,n)Be^8$ reaction ($E_n \lesssim 24$ Mev). In addition to well-known radiations, a beta spectrum with an end point of 5.05 ± 0.25 Mev and two gamma rays with energies of 2.26 ± 0.03 and 3.52 ± 0.03 Mev were observed. These gamma rays and the beta group decayed, within experimental error, with the same half-life, 3.27 ± 0.20 sec. The assignment of this activity to Al^{30} and the proposed decay scheme are supported by considerations involving the decay schemes of the well-known isotopes produced, half-life studies using portions of both the beta and gamma spectra, the features of experimental beta and gamma spectra, and nuclear systematics. Strong beta transitions to the first and second excited states of Si^{30} are inferred from the experimental gamma spectrum and nuclear systematics. A weak beta transition (<2%) to the ground state cannot be excluded by this investigation. Possible spin and parity assignments for the ground state of Al^{30} are 1+, 2+, and 3+. A weak argument is made against a spin 1 assignment. The results of this investigation cannot be used to reduce the ambiguity of the spin assignment further. The resulting Al^{30}–Si^{30} mass difference is 7.29 ± 0.25 Mev.

I. INTRODUCTION

IN connection with a study of short half-lived isotopes, a search was made for the previously unobserved isotope, Al^{30}. The calculated mass excess of Al^{30} using the semiempirical formulas of Cameron[1] and Fermi[2] is -6.82 and -9.95 Mev, respectively. These mass values indicate that the ground state of Al^{30} should be stable to heavy particle emission and should negatron decay to Si^{30} with a total disintegration energy of $\sim$8.8 or $\sim$5.6 Mev, depending on whether the Cameron or Fermi Al^{30} mass excess is used. Furthermore, assuming a single allowed beta transition to the Si^{30} ground state, a half-life value in the range from 0.1 to 10 sec would be expected.

This investigation was undertaken to produce Al^{30} by bombarding natural silicon with fast neutrons and to study its decay modes using scintillation techniques.

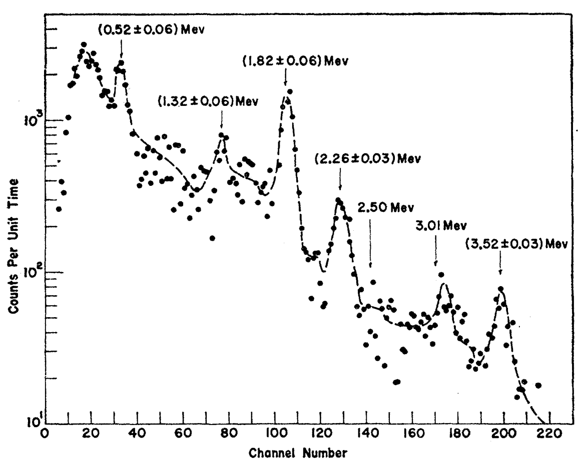

FIG. 1. A gamma-ray spectrum from high-purity natural silicon targets after bombardment with fast neutrons. The spectrum was formed from a series of difference spectra. Each difference spectrum was formed by taking a 5-sec spectrum accumulated 0.32 sec after a 3.5-sec bombardment and subtracting from it a 5-sec spectrum accumulated 10.32 sec after the same bombardment.

II. EXPERIMENTAL APPARATUS AND PROCEDURE

Most of the experimental apparatus and techniques employed in the present investigation have been described elsewhere.[3,4] The important points of difference in experimental detail will be described below.

The neutron source was a lithium metal target which was bombarded with the 9.7-Mev external deuteron beam from the Purdue University 37-in. cyclotron. The external deuteron beam was focused by a set of quadrupole magnets, collimated, passed through a 1-mil aluminum window, $\frac{3}{8}$ in. of air, and a second 1-mil aluminum window before impinging on a $\frac{1}{16}$-in. thick, water-cooled lithium target. The nominal deuteron beam current and energy at the lithium target were 0.5 μa and 8.8 Mev, respectively. The Q value for the reaction $Li^7(d,n)Be^8$ is about 15 Mev and the energy spectrum is known to be complex. A continuous neutron spectrum with a maximum energy of about 24 Mev could be expected. The predicted Q value for the reaction $Si^{30}(n,p)Al^{30}$ is -8 or -5 Mev according as the Cameron or Fermi value of the Al^{30} mass excess is used.

The targets consisted of high-purity silicon cylinders ($\frac{3}{4}$ in. in diameter and $\frac{3}{8}$ in. in thickness). The maximum total impurity in this silicon was of the order of 10 parts per million. The silicon cylinders were mounted on polystyrene target carriers. Three targets that could be interchangeably mounted on different target carriers were used to avoid excessive buildup of longer-lived activities in the silicon and to allow the investigation of the contributions to the beta and gamma spectra arising from induced activities in materials of the target carrier and target-carrier hardware. The latter contributions to the spectra were found to be negligible. During bombardment the silicon target was located directly behind the lithium container, about $\frac{1}{4}$ in. from the lithium,

† This work was supported in part by the U. S. Atomic Energy Commission and is based on a part of the doctoral thesis research of E. L. Robinson.

[1] A. G. W. Cameron, Atomic Energy of Canada Limited, Report 433, CRP-690, 1957 (unpublished).

[2] N. Metropolis and G. Reitwiesner, Atomic Energy Commission Report NP-1980, 1950 (unpublished).

[3] E. L. Robinson and O. E. Johnson, Phys. Rev. **120**, 1321 (1960).

[4] E. L. Robinson, B. T. Lucas, and O. E. Johnson, Phys. Rev. **122**, 202 (1961).

within the pneumatic target-transfer tube. After a predetermined bombardment period the target-transfer system, which was integrated with the spectrometer and half-life circuits, transported the silicon targets to the counters 19 ft away. The travel time for the silicon and target carrier during these investigations was nominally 0.33 sec.

The gamma rays were detected with a cylindrical 3×3-in. NaI(Tl) crystal optically coupled with Dow Corning 200 fluid to a DuMont type 6363 photomultiplier tube. The gamma detector was mounted coaxially with the beta detector and on the opposite side of the source from it. Lucite absorbers were placed in front of the gamma detectors to stop the beta particles. The resolution for the 0.662-Mev gamma ray of Ba^{137m} was 9%.

The beta detector consisted of a cylindrical plastic phosphor ($2\frac{1}{2}$ in. in diameter ×$1\frac{1}{2}$ in. in height) optically coupled to a DuMont type 6363 photomultiplier tube with Dow Corning QC-2-0057 silicone compound.[5] The phosphor was covered with a thin aluminum light cover which had been smoked on the inside with MgO. Beta particles entered the phosphor through a 1-mil aluminum window. The resolution obtained with this detector for the 0.624-Mev internal conversion line of Ba^{137m} was 15%.

The beta and gamma detectors were energy-calibrated with several standard sources. Photopeaks from gamma rays of known energy were used for gamma-energy calibration. Beta-spectra end points and internal conversion lines of well-known energies were used for beta-energy calibration.

The detector output was passed through a preamplifier either to the multichannel pulse-height analyzer or to the circuit configuration used for half-life analysis.

III. MEASUREMENTS, RESULTS, AND DISCUSSION

Many nuclear reactions are energetically possible when natural silicon is bombarded with neutrons having an energy distribution that extends to 24 Mev. Identification of the product radioisotopes was accomplished through consideration of the results of half-life measurements made using various portions of the beta and gamma spectra and measurements of the total beta and gamma spectra.

The measurements of beta and gamma spectra were made according to the following general program: The target was irradiated T_B sec; the start of the first counting period was delayed T_{D1} sec after the end of the bombardment; the spectrum was measured for T_{C1} sec; a second delay of T_{D2} sec followed the measurement; finally a second measurement of the spectrum was made for T_{C2} sec. A difference spectrum was formed from these two spectra. A series of similar measurements was made and the resulting difference spectra were summed to form the final spectrum. Since Si^{30} is only 3.1% abundant, the activity of interest was relatively weak, thus many cycles of the program were necessary. The experimental points in the resulting spectrum represent the difference of two numbers, the smaller of these numbers being equal to or greater than their difference, so have rather large statistical errors.

A preliminary gamma spectrum was measured with $T_B=2.2$ sec, $T_{D1}=0.33$ sec, $T_{C1}=60$ sec and no subtraction of a second spectrum. This spectrum favored observation of the longer-lived activities and could be interpreted, except for peaks at ~2.3 and ~3.5 Mev, by assuming that Al^{28}, ~2.3 min; Al^{29}, ~6.6 min; Si^{27}, ~4.1 sec; and Si^{31}, ~2.6 hr were produced during the bombardment.[6] Gamma-ray spectra measured with shorter T_{C1} periods showed enhancement, relative to the remainder of the spectrum, of the peak interpreted as annihilation radiation and the peaks at ~2.3 and ~3.5 Mev. Spectra measured using various T_{D1} intervals indicated the half-life of the unassigned activity to be in the range from 1 to 10 sec. A spectrum was measured with $T_B=3.5$ sec, $T_{D1}=0.33$ sec, $T_{C1}=5.0$ sec, $T_{D2}=5.0$ sec, and $T_{C2}=5.0$ sec. This spectrum showed the following gamma rays (see Fig. 1): 0.52 ±0.06 Mev, interpreted as annihilation radiation due to the presence of the 4.1-sec positron emitter Si^{27} and external pair production; 1.32±0.06 Mev, due possibly to both the Si^{31} and Al^{29} decays and there may also be a contribution resulting from the gamma transition between the 3.51-Mev and 2.24-Mev levels of Si^{30}; 1.82 ±0.06 Mev, from the decay of Al^{28}; and peaks at 2.26 ±0.03 Mev and 3.52±0.03 Mev which cannot be associated with the decay of any known product isotope. The intensity of the 3.52-Mev radiation relative to the 2.26-Mev radiation is 0.64±0.06. The peak at ~3.0 Mev and the small peak at ~2.5 Mev are interpreted as the single and double escape peaks of the 3.52-Mev gamma ray. The large scattering of points in the energy interval around 2.5 Mev is attributed to the large statistical fluctuations arising from the subtraction of the 2.43-Mev gamma ray of Al^{29}. No evidence was found for any other gamma rays below 5.5-Mev. The assigned energy errors are estimated limits of error based on an appraisal of calibration procedures, uncertainty in peak location, and count-rate effects.

The half-life measurements were made by passing energy-selected pulses from the detector into the multichannel analyzer used in its time-analysis mode.[3] Half-life measurements using all gamma radiation with

[5] C. E. Crouthamel, *Applied Gamma-Ray Spectrometry* (Pergamon Press, New York, 1960), p. 63.

[6] It may be generally assumed, unless otherwise specified, that properties of nuclei referred to in this report have been selected from one or more of the following compilations of nuclear data: P. M. Endt and C. M. Braams, Revs. Modern Phys. **26**, 683 (1957); D. Strominger, J. M. Hollander, and G. T. Seaborg, *ibid.* **30**, 584 (1958); F. Ajzenberg-Selove and T. Lauritsen, Nuclear Phys. **11**, 1 (1959); and *Nuclear Data Sheets* (National Academy of Science—National Research Council, Washington, D. C., 1958–1960).

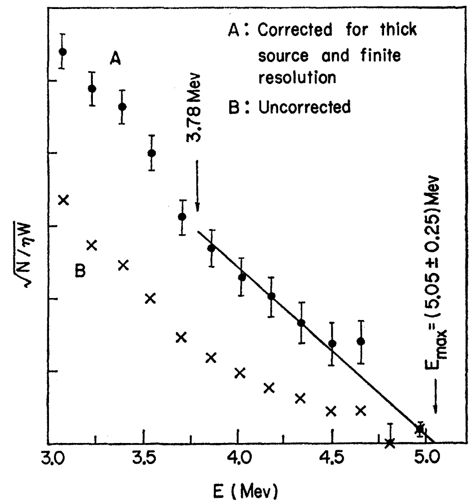

FIG. 2. A conventional Fermi plot of a portion of the beta spectrum associated with the decay of radioisotopes produced by the neutron irradiation of thick natural silicon targets. The Fermi function was assumed to be a constant. The points marked A have been corrected for target thickness and finite resolution. The points marked B represent the data before correction. See the text for details.

$E\geq 2.0$ Mev and $E\geq 2.1$ Mev each yielded a single short-lived component (2.97 ± 0.60 and 3.26 ± 0.50 sec, respectively). A half-life of 3.33 ± 0.50 sec was measured for the gamma radiation in a 320-kev interval centered at 3.52 Mev. The activity associated with an energy greater than 3 Mev, observed using the beta detector, yielded a single short-lived component with a (3.52 ± 0.40)-sec half-life. The errors are estimated limits of error based on counting statistics and an appraisal of the errors associated with the methods used in the analysis of the data. These half-lives are, within experimental error, consistent and yield an average value of 3.27 sec with a standard deviation of 0.20 sec.

Limited neutron flux, a relatively low reaction cross section, and the low natural isotopic abundance of Si^{30} dictated the use of extremely thick silicon targets (nominally 2.3 g/cm^2). The short half-life ruled out chemical separations and required that the entire silicon target be used as an Al^{30} beta source. The neutron flux in the targets should be almost constant. As a consequence of this, correspondingly uniform production of Al^{30} could be expected throughout the silicon. The beta spectra were measured using extremely thick sources. A conventional Fermi plot constructed using the experimental data is shown in Fig. 2, the set of points marked B. The marked deviation from linearity in the high-energy region is interpreted as arising from the extreme source thickness and finite resolution. A first-order correction for both source thickness and finite resolution was calculated. This correction was applied to the experimental data and yielded the set of points marked A in Fig. 2. The curvature in the corrected Fermi plot is reduced in the energy interval between 3.8 and 5.0 Mev. A linear least-squares fit of the corrected data between 3.8 and 5.0 Mev yields an end-point energy of 5.05 ± 0.25 Mev. The error is an estimated probable error with the largest contribution coming from the correction itself. The points below 3.8 Mev were not used to make the fit since a deviation from linearity in the Fermi plot would be expected to start at about 3.78 Mev due to the beta transition which populates the second excited state of Si^{30} if the 5.05-Mev transition is to the first excited state.

The (3.27 ± 0.20)-sec activity is assigned to the decay of Al^{30} on the basis of the following observations: (1) The activity is not associated with materials in the target-transfer system, impurities inherent to the silicon, or surface contaminants on the silicon targets; (2) failure of one or more of the features of the experimental gamma spectrum to correspond to details of the composite gamma spectrum expected from the known reaction products; (3) failure of the end-point energy of the beta spectrum to correspond to that of beta transitions in known reaction products; (4) inability to associate the (3.27 ± 0.20)-sec half-life obtained from various types of measurements using beta and gamma radiation with previously observed reaction products which have been identified in this investigation; and (5) the correspondence between the observed gamma-ray energies and the known states in Si^{30}. It will be assumed for the remainder of this report that the radiations in question are associated with the decay of Al^{30} to Si^{30}.

The quantity of the (3.27 ± 0.20)-sec radioisotope

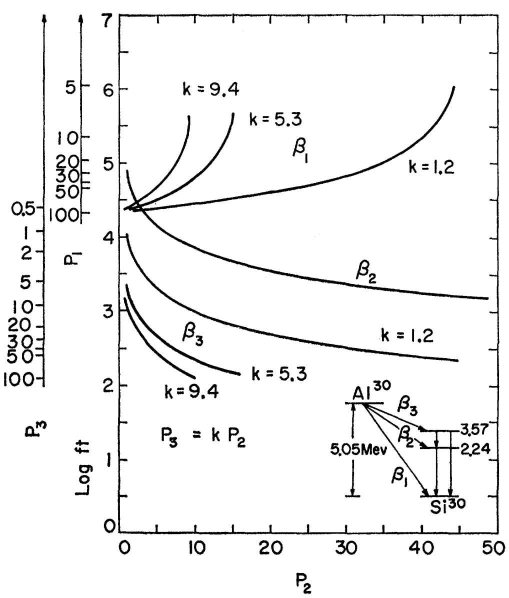

FIG. 3. The partial decay scheme is an assumed trial decay scheme for Al^{30}. The total disintegration energy is taken to be 5.05 Mev. The log ft values for the three beta transitions are shown as a function of P_2 for various values of the (P_2,P_3) ratio, and may be read off the ordinate scale. The two separate auxiliary ordinate scales are used to read the branching percentages P_1 and P_3. See the text for details and discussion.

produced in these investigations was small rendering the use of coincidence techniques completely impractical. As an immediate consequence, direct experimental information as to whether the Al^{30}-Si^{30} mass difference is 7.29 or 5.05 Mev could not be obtained. In order to further investigate this point, less direct experimental information will be combined with nuclear theory and systematics. Since no evidence was found for transitions from the Al^{30} ground state to any state higher than the second excited state of Si^{30}, it shall be assumed throughout the following discussion that there are only three beta transitions. In particular, the assumed transitions are: β_1 to the (0+)-ground state; β_2 to the (2+)-first excited state at 2.24 Mev; and β_3 to the second excited state at 3.51 Mev. The branching percentages of these beta transitions shall be denoted by P_1, P_2, and P_3.

The Al^{30}-Si^{30} mass difference will be 7.29 or 5.05 Mev according as the measured (5.05 ± 0.25)-Mev end point is that of β_1 or β_2. First, assume the total Al^{30}-Si^{30} disintegration energy is 5.05 ± 0.25 Mev as shown in the decay scheme of Fig. 3. The intensity of the 3.51-Mev gamma transition relative to the 2.24-Mev gamma transition was measured to be 0.64 ± 0.06. The intensity of the 3.51-Mev gamma transition to the 1.27-Mev gamma transition, the transition between the first and second excited states, has been reported as 0.87 ± 0.17.[7,8] Combining this experimental information one finds that $P_3=(5.3\pm3.9)P_2$. Figure 3 is a graphical representation of the implications of the experimental information and this assumed decay scheme. The curves represent the $\log ft$ values for β_1, β_2, and β_3 as a function of P_2. The abscissa scale is used for the variable P_2. The $\log ft$ values for each of the transitions may be read off the common ordinate scale. The separate, auxiliary ordinate scales are used to read P_1 and P_3, the branching percentages of β_1 and β_3. Three pairs of curves for β_1 and β_3 correspond to three values of the (P_3,P_2) ratio. Examination of the curves reveals that in order to have the comparative half-lives of β_2 and β_3 in the range normally associated with allowed transitions requires that $P_2\lesssim1\%$ implying that $P_1>90\%$; that is, more than 90% of the transitions go to the ground state of Si^{30}. It then follows that the ratio of the intensity of beta radiation to gamma radiation should be at least 10 and possibly 100 or more. Crude experimental determinations of this ratio, believed to be reliable to a factor of 2 or 3, prove that this firm lower limit on the predicted ratio of 10 is not approached. On this basis, it is concluded that the total disintegration energy is not 5.05 ± 0.25 Mev.

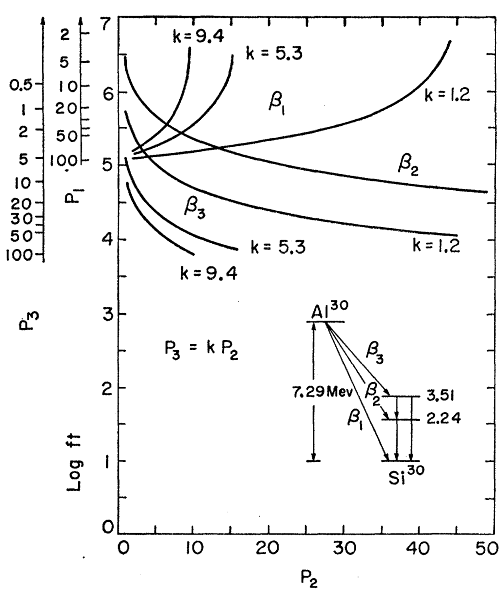

FIG. 4. Same as Fig. 3 except that the Al^{30}–Si^{30} mass difference is assumed to be 7.29 Mev.

In Fig. 4 a plot is shown which is similar in structure to that of Fig. 3. The assumptions are the same except β_2 is assumed to be the 5.05-Mev transition as shown in the decay scheme. A firm experimental upper limit of 2% has been placed on the intensity of a (7.29 ± 0.25)-Mev beta transition; that is, $P_1<2\%$. Referring to the curves for the most probable value of the (P_2,P_3) ratio, $k=5.3$, the corresponding approximate $\log ft$ values and branching percentages for β_2 and β_3 are (5.2 and 16%) and (3.9 and 83%), respectively. The comparative half-life of β_2 is in the allowed range, but the value for β_3 is slightly low. This latter point will be discussed below. The assumptions associated with construction of the curves of Fig. 4 lead to consequences that are more generally consistent with the experimental results.

The general trend in the energy difference between the lowest levels of isotopic spin $T=1$ and $T=2$ as a function of mass number for light nuclei of the type $A=4n+2$ appears to favor a (7.29 ± 0.25)-Mev Al^{30}-Si^{30} mass difference. Using the notation and following the method of Peaslee,[9] the Coulomb energy differences of these light nuclei, determined from more recent and more complete beta decay data were fitted to the form

$$\Delta E_c=a[(Z+\tfrac{1}{2})/A^{\frac{1}{3}}]+b, \qquad (1)$$

where Z is the lower atomic number of the two nuclei connected by the beta decay, a and b are constants, and A is the mass number. The new values of the constants are $a=1.451$ Mev and $b=-1.088$ Mev. This Coulomb energy expression was used with experimental decay energies to determine Δ_{21}, the energy separation between the lowest levels of isotopic spin $T=1$ and $T=2$ for a given A. This quantity can be obtained from the energy available for the appropriate ($T=2$) ground state to ($T=1$) ground state negatron transition, E_{β^-}:

$$\Delta_{21}=E_{\beta^-}+\Delta E_c-0.783 \text{ Mev}$$
$$=E_{\beta^-}+1.451[(Z+\tfrac{1}{2})/A^{\frac{1}{3}}]-1.871. \qquad (2)$$

[7] C. Broude and H. E. Gove, Bull. Am. Phys. Soc. 5, 248 (1960).
[8] H. E. Gove (private communication).

[9] D. C. Peaslee, Phys. Rev. 95, 717 (1954).

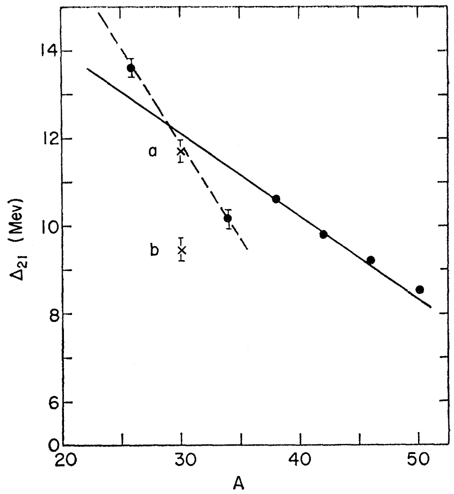

FIG. 5. A plot of the energy separation between the lowest levels of isotopic spin $T=2$ and $T=1$ for a given A in light nuclei of the $(4n+2)$ type. The two points at $A=30$ represent the values of Δ_{21} resulting from the assumed Al^{30}–Si^{30} mass differences of 7.29 Mev, point labeled *a*, and 5.05 Mev, point labeled *b*. (*Note added in proof*. Point at $A=26$ should be plotted at 12.3 Mev with corresponding change in broken line.)

A plot of Δ_{21} for $(4n+2)$-type nuclei is shown in Fig. 5. The points marked with crosses correspond to the alternate values for the Al^{30}-Si^{30} mass difference. The solid line was fitted by least squares to all the points marked with solid circles. The broken line connects the points at $A=26$ and 34. Whether one assumes that all the points should lie close to the solid line, or that there is a break in the line at $A=38$ and the points for $A<38$ should lie close to the broken line, a mass difference of 7.29 ± 0.25 Mev is favored. More detailed examination of other nuclear systematics indicate that the curve through the points should be in two parts with a discontinuity between $A=34$ and 38 arising from the closing of a neutron shell at the magic number 20.

Simple shell-model considerations result in the alternative spin assignments 1 through 5 and positive parity for the Al^{30} ground state. From Fig. 4 and its associated discussion, it is concluded that the beta transitions β_2 to the $(2+)$, 2.24-Mev state and β_3 to the $(2+)$, 3.51-Mev state[8] of Al^{30} are of an allowed character, thus inferring the alternative spin assignments 1, 2, or 3 and even parity. The ambiguity in this spin assignment could be further reduced if β_1 could be shown to be forbidden character. It has been established experimentally that P_1 is definitely less than 2% and is, with high probability, much less than this upper limit. A β_1 branching percentage of 2% corresponds to a comparative half-life of 6.8 which is somewhat outside the "normal" allowed range. Though classification of a beta transition as forbidden solely on the basis of its comparative half-life is a questionable procedure, except in extreme cases, the possibility of P_1 being much less than 2% can be interpreted as weak support for the assertion that of the remaining alternative spins 1, 2, and 3 an assignment of 1 is the least probable. Brennan and Bernstein[10] proposed an empirical coupling rule for configurations in which there is a combination of particles and holes (a $d_{\frac{5}{2}}$ proton hole and a $d_{\frac{3}{2}}$ neutron in the case of Al^{30}). This rule predicts 3 for the spin, which is compatible with the results of this investigation.

Although the comparative half-life of β_2 is within the range expected for allowed transitions, that of β_3 seems slightly low. One early experiment[11] indicated the gamma transition from the second to the first excited state in Si^{30} to be weak. If this branching ratio is in the lower portion of the range of values covered by the experimental ratio, 0.87 ± 0.17, and/or there are undetected beta transitions to higher states which decay through the 3.51-Mev level such that the order associated gamma radiation is masked by more prominent features of the gamma spectrum, then the assumptions that have been made would lead to a low comparative half-life for β_3.

IV. CONCLUSIONS

Experimental results have been presented and interpreted within the framework of pertinent nuclear theory and systematics to yield the following conclusions: (1) A radioisotope with a (3.27 ± 0.20)-sec half-life is produced by bombarding silicon with (Li^7-d) neutrons. (2) This activity is that of the previously unobserved isotope Al^{30} and is produced by the reaction $Si^{30}(n,p)Al^{30}$. (3) The decay of the Al^{30} ground state takes place by at least two beta transitions. (4) A (5.05 ± 0.25)-Mev beta transition, β_2, is the principal mode of decay. (5) An upper limit of $\sim2\%$ is placed on

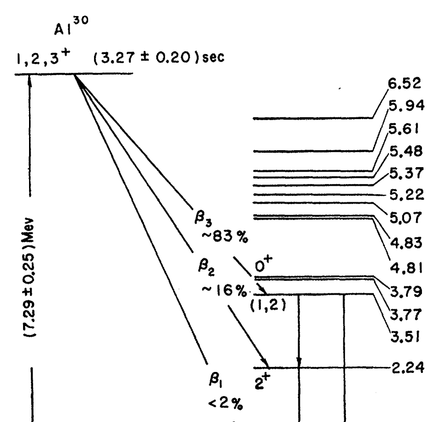

FIG. 6. The level structure of Si^{30} taken from recent compilations of nuclear data (see reference 6), and the proposed decay scheme of Al^{30} resulting from the present investigation.

[10] M. H. Brennan and A. M. Bernstein, Phys. Rev. **120**, 927 (1960).

[11] H. H. Landon, Phys. Rev. **83**, 1081 (1951).

the branching percentage of a (7.24±0.25)-Mev beta transition, β_1. (6) Two gamma transitions, having energies of 2.26±0.03 Mev and 3.52±0.05 Mev are associated with the decay of Al^{30}. The intensity of the 3.51-Mev gamma ray relative to that of the 2.24-Mev gamma ray was measured to be 0.64±0.06. (7) Since limited source strength prevented coincidence measurements, the Al^{30}-Si^{30} mass difference is either (5.05±0.25) Mev or (7.29±0.25) Mev with the latter value more consistent with nuclear systematics and indirect experimental results. (8) Shell-model considerations yield alternative Al^{30} ground-state spin assignments 1 through 5 and even parity. Although no further reduction in the spin ambiguity can be made directly from the present experimental results, reasonable arguments can be made to reduce the choice to the values 1, 2, or 3 with 1 being the least probable. (9) The proposed decay scheme for Al^{30} is shown in Fig. 6.

ACKNOWLEDGMENTS

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New Hafnium Isotope, Hf^{182}†

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A new isotope of hafnium, Hf^{182}, has been produced by double neutron capture in Hf^{180} in the intense neutron flux of the materials testing reactor (MTR). Mass spectrometric analysis of the irradiated hafnium gave a Hf^{182}/Hf^{180} atom ratio of 0.00147±0.00001. The new isotope decays with a half-life of $(9\pm2)\times10^6$ years by β^- emission predominantly to a 271-kev level in Ta^{182}. The number of 271-kev gamma rays per β^- disintegration is 0.84±0.10. The log ft for the beta transition to the Ta^{182} ground state is >15 indicating that this transition is at least third forbidden. The neutron capture cross section of Hf^{181} is 40_{-20}^{+40} barns.

In a continued search for extinct radioactivities, several nuclides were exposed to the high neutron flux of the materials testing reactor in September, 1956, for a one-year irradiation. One of these targets was 300 mg of HfO_2, enriched in Hf^{180} to 93%. Approximately three years after the completion of the irradiation, when the Hf^{181} and Hf^{175} activities had decayed by factors of many thousands, the sample was dissolved by fusion with $K_2S_2O_7$. Following several chemical purifications of the hafnium, a small sample was isotopically analyzed in a 12-in., 60° mass spectrometer with a multiple-rhenium-filament ionization source. The hafnium isotope Hf^{182} was detected in the amount given in Table I.

The radiations of Hf^{182} were examined with 3×3-in. NaI(Tl) and $\frac{1}{4}$-in. thick anthracene crystal detectors coupled with conventional amplifiers and multichannel analyzer. The γ ray spectrum of the chemically purified hafnium sample contained, in addition to the photopeaks characteristic of the decay of Hf^{181} (45 days) and Hf^{175} (70 days), a 271-kev γ ray which is associated with the decay of Hf^{182}. The intensity of the 271-kev γ ray is 0.84±0.10 per Hf^{182} disintegration.

The results of the measurement on the beta spectrum are indefinite due to the Hf^{181} contribution, although an upper limit of 0.4 Mev can be placed on the beta particles of Hf^{182}.

The half-life of Hf^{182} was determined from the growth rate of Ta^{182}. In order to discriminate against the Hf^{175} and Hf^{181} activities, the Ta^{182} was detected by its gamma rays with energy greater than 1 Mev. The absolute counting efficiency of Ta^{182} gamma rays in the energy range selected in our experiment was established by comparing the gamma-ray counting rate of a pure Ta^{182} activity in our arrangement with its beta counting rate in a 4-π beta counter. The amount of Hf^{182} was calculated from the mass spectrometric analysis and the

TABLE I. Isotopic content of hafnium sample enriched in Hf^{180} and irradiated in the MTR for 1 year.

Isotope	Atom percent
182	0.138±0.001
180	93.80 ±0.04
179	3.16 ±0.03
178	2.67 ±0.03
177	0.098±0.002
176	0.114±0.005
174	0.023±0.001

† Based on work performed under the auspices of the U. S. Atomic Energy Commission.