reagent was then added to precipitate the vanadium. The precipitate was centrifuged and washed with 4 percent H_2SO_4.

The vanadium precipitate was then mounted in planchet and counted. Absorption curves taken at two-day intervals indicate a beta with an energy of 0.56±0.1 Mev.[1]

Gamma-ray spectra of the vanadium precipitate were obtained using a sweep-type differential and integral discriminator, similar to the one already described by Fairstein.[2]

Measurements from the decay curve and from the gamma-ray spectra indicate the half-life of V^{53} to be 23±1 hours.

The number of gamma rays shown by the gamma-ray spectra data indicate a complex decay scheme for V^{53}.

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Work is continuing on this nuclide.

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[1] An isotope of vanadium with a 23-hour half-life and ~0.6-Mev β^- has been observed by L. Hsiao and R. B. Duffield (private communication from R. B. Duffield).

[2] E. Fairstein, Rev. Sci. Instr. 22, 76 (1951).

Spins of the Lowest States of the K^{40}, P^{32}, and Al^{28} Nuclei

HARALD A. ENGE
Department of Physics, University of Bergen, Bergen, Norway

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COMPOUND nucleus theories as well as stripping theories of nuclear reactions predict the differential cross section at a given reaction angle to vary with the spin I of the final nuclear state. Because there are as a rule other unknown parameters and because of the approximate nature of the theories, a predicted spin dependence is in general of little value for determining the spins of nuclear states. In certain special cases, however, the dependence might be useful, namely for levels that are members of closely spaced (j,j) multiplets where the only parameter differing appreciably from state to state is the resultant spin. The simplest cases are perhaps those stripping processes in which the captured particle can be assumed to go directly into a vacant "orbit" without appreciably agitating the target "core."

In stripping theories the cross section is expressed as a sum over all channels allowed by conservation rules of angular momentum and parity. In the simple cases mentioned above, however, the shell model (insofar as it is valid) requires that the captured particle brings with it the right orbital angular momentum $l\hbar$ and has the right spin direction. In that case the number of open channels are the same as the number of degeneracies of the final state or $(2I+1)$. When the energy separations between multiplet states are small, the variation in yield from state to state will be determined mainly by this factor. Because the states considered all have the same l value for the captured particle, the angular distributions are the same or very nearly so.

The compound nucleus theory of Wolfenstein[1] gives predictions about angular distributions and about the variation of the average cross section with spin of the final state, among other things. The experimental relative (d,p) yields considered in this letter have been measured at a reaction angle $\theta_{\mathrm{lab}}=90$ degrees, with incident deuteron energies from 2 to 5 Mev and emerging proton energies above 7 Mev. From Wolfenstein's work it may be inferred that it is a fairly good approximation for these cases to assume a $(2I+1)$ dependence also for the part of the cross section that is due to compound nucleus formation.

Various experimental data concerning the lowest states of K^{40}, P^{32}, and Al^{28} have been collected in Table I. The combinations of odd-proton and odd-neutron states expected to yield the lowest levels are given in column 2. Two possible configurations are given for Al^{28}. Apparent disagreement between experimental data prevents one at the moment from deciding between the alternatives. The lowest states observed[2-4] (column 3) are tentatively assumed to be members of the (j,j) multiplets in column 2. (These assumptions are not very well founded, especially for the two higher levels in K^{40}.)

Results from the stripping analysis[5-8] of angular distribution data are quoted in column 4 for the unresolved P^{32} and Al^{28} doublets. As judged from available experimental data, small contributions from larger orbital angular momentum values (e.g., $l_n=2$) cannot be entirely excluded in the Al^{28} case. Spin values compatible with the measured l_n values are given in column 5 and other restrictions on the spins in column 6 [from β decays and (n,γ) measurements]. Suggested final spin assignments for the various levels are presented in column 7. They are based on all available data and also on relative yields. The relative yields expected when employing the $(2I+1)$ rule are given in column 8 (I_0=ground-state spin). These figures should be compared with the experimental values in column 9.

For the $P^{31}(d,p)P^{32}$ stripping process also, $l_n=0$ is allowed for the ground state by ordinary conservation rules. The fact that only $l_n=2$ occurs is a great tribute to the shell model[7,9] and it proves that one of the basic ideas behind the $(2I+1)$ rule is correct. This rule is further based on the assumption that in stripping processes only one spin direction is allowed for the incident particle when forming a specific state. The ordinary law of conservation of angular momentum very often allows different numbers of incident spin directions (1 or 2) for different members of the same multiplet (l_n given). An approximate validity of the $(2I+1)$ rule in such cases for pure stripping would further strengthen the view that shell-model considerations should be taken into account when describing these processes. The measured (d,p) yields referred to

TABLE I. Suggested spin assignments for the lowest states of K^{40}, P^{32}, and Al^{28}, partly based on the assumption that the (d,p) yield is proportional to $(2I+1)$.

Nucl.	Assumed config. of multiplet	Exc. energy Mev	Stripping data l_n	Stripping data I	Other spin data	Final spin assign.	$\frac{(2I+1)}{(2I_0+1)}$	Exper. yield ratio
K^{40}	$(d_{3/2},f_{7/2})$	0			4	4^-	1	1
		0.032^a			$\leq 3^f$	3^-	0.78	0.8^i
		0.800^a			$\leq 3^f$	2^-	0.56	0.6^i
		0.893^a			$\geq 4^f$	5^-	1.22	1.1^i
P^{32}	$(s_{1/2},d_{3/2})$	0	2^d	1, 2, (3)	$0, 1^g$	1^+	1	1
		0.077^b	2^d	1, 2, (3)		2^+	1.67	1.5^j
Al^{28}	$(d_{5/2},s_{1/2})$ or $(d_{5/2},d_{5/2})$	0	0^e	2, 3	$2, 3^g$	3^+ or 2^+	1	1
		0.031^c	0^e?	2, 3	1^h	2^+ or 1^+	0.71 (0.60)	0.63^k

[a] See reference 2. [b] See reference 3. [c] See reference 4. [d] See references 6 and 7. [e] See references 5, 6, and 8. [f] From $K^{39}(n,\gamma)K^{40}$ yields. See reference 2 and G. A. Bartholomew and B. B. Kinsey, Can. J. Phys. **31**, 927 (1953). [g] From β decay. Further references given in Hollander, Perlman, and Seaborg, Revs. Modern Phys. **25**, 469 (1953). [h] From β decay of Mg^{28}. Also $\Delta I \leq 1$ between states. See A. H. Wapstra and A. L. Veenendaal, Phys. Rev. **91**, 426 (1953). [i] Taken out of Fig. 1 in reference 2. $E_d=5$ Mev. [j] Average for $E_d=1.8$ and 2 Mev. See reference 3. [k] Average for $E_d=1.5$, 1.8, 2.1, and 5.2 Mev. Author's results and W. W. Buechner (private communication).

in Table I are probably in large part due to compound nucleus formation.

[1] L. Wolfenstein, Phys. Rev. **82**, 690 (1951).
[2] Buechner, Sperduto, Browne, and Bockelman, Phys. Rev. **91**, 1502 (1953).
[3] Van Patter, Endt, Sperduto, and Buechner, Phys. Rev. **86**, 502 (1952).
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Bubble Tracks in a Hydrogen-Filled Glaser Chamber*

JOHN G. WOOD
Radiation Laboratory, Department of Physics, University of California, Berkeley, California

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GLASER[1] first showed that the boiling of superheated ethyl ether was sensitive to ionizing radiation, and later photographed the bubble tracks in his apparatus. A liquid-hydrogen chamber would have a number of attractive features, and it is therefore not surprising that several groups have been working to produce such a device. At Chicago, Hildebrand and Nagle,[2] working in cooperation with Glaser, have produced superheated liquid hydrogen, and have shown that it boils sooner in the presence of a γ-ray source. We have taken the next step, but with somewhat different technique, and can report the photography of bubble tracks in hydrogen. (See Fig. 1.)

The bulk of the Chicago apparatus was immersed in a bath of hydrogen which was boiling at atmospheric pressure, but the bubble chamber was in the vapor space, and superheated by a coil of resistance wire. This arrangement involves problems of heat transfer and temperature measurement, in addition to some serious problems if photography were to be attempted. We have therefore immersed our bubble chamber in a bath of hydrogen which boils at high pressure; this provides a convenient heat reservoir, whose temperature is easily controlled by a pressure regulator. First, hydrogen is condensed into the bubble chamber at a pressure somewhat higher than that over the bath. After temperature equilibrium has been established, the following cycle is initiated: (1) The pressure in the bubble chamber is suddenly reduced to one atmosphere. (2) At a variable time after the pressure release, an electronic circuit triggers a stroboscopic lamp, which takes a photograph of the chamber, and (3) pressure is reapplied to the chamber to condense any bubbles that may have formed.

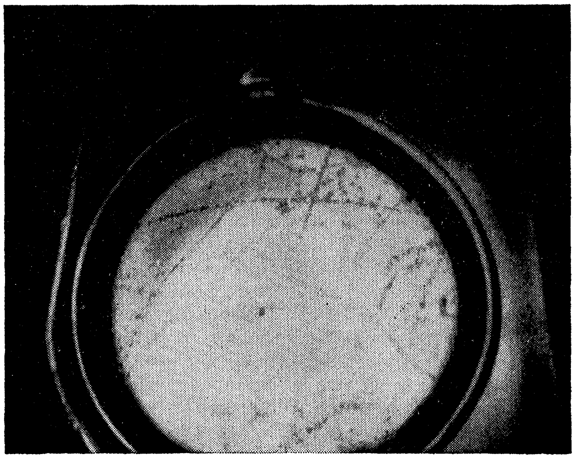

FIG. 1. 1½-inch chamber irradiated with a Po-Be source.

We have been unable to duplicate the long times of superheat reported by the Chicago group, but we have been using considerably higher degrees of superheat. We were discouraged by our inability to attain the long times of superheat, until the track photographs showed that it was not important in the successful operation of a large bubble chamber. Tracks have even been observed in cases where the liquid hydrogen was not completely condensed in the chamber prior to expansion.

I wish to thank Dr. Luis W. Alvarez, Dr. Frank S. Crawford, Jr., and Dr. M. Lynn Stevenson for their advice and help in these experiments. I am indebted to A. J. Schwemin for help with the electronic circuits, and to H. Powell and T. Robbins for their cooperation with the glass work.

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[2] R. H. Hildebrand and D. E. Nagle, Phys. Rev. **92**, 517 (1953).

Angular Distribution of Deuterons from $N^{14}(p,d)N^{13}$†

K. G. STANDING*
Palmer Physical Laboratory, Princeton University, Princeton, New Jersey

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BUTLER'S interpretation[1] of the angular distribution of particles from (d,p) and (d,n) stripping reactions has yielded much information on the spins and parities of nuclear states.[2] By the reciprocity theorem,[3] a similar analysis should apply to the inverse processes, (p,d) and (n,d) pickup. Most pickup reactions have Q's which are negative and several Mev in magnitude, so it is necessary to select low-energy deuteron groups in the presence of background caused by relatively high-energy protons. Because of this difficulty, angular distributions from (p,d) reactions have been examined in a few favorable cases[4,5] only.

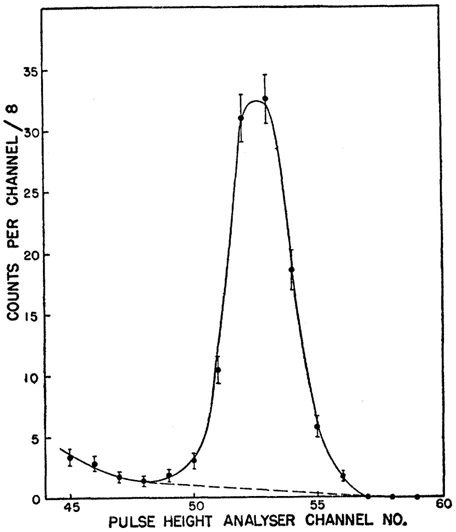

FIG. 1. Gated scintillation counter spectrum at 15° in the laboratory system. The peak consists of $N^{14}(p,d)N^{13}$ ground-state deuterons. Background was estimated from the general shape of the curve and from spectra taken with larger absorbers (which move the deuteron peak to a lower pulse height).

A thin NaI crystal in a scintillation counter may be used to distinguish deuterons from proton background. The maximum possible energy loss of any deuteron passing normally through such a crystal comes from a deuteron whose range in NaI is equal to the thickness T of the crystal. This deuteron *just* stops in the crystal and loses its entire energy E_T. A higher-energy deuteron will pass through the crystal and lose energy $<E_T$ because of the smaller rate of energy loss at higher energy. A similar relation holds for protons, but, since the range of a proton is greater than the range