

FIG. 2. Number of neutrons per 50 keV interval versus neutron energy for $\bar{E}_p = 3.800$ Mev at 45° and 90° .

as was described earlier.¹ In this case, the targets were approximately 30 keV thick foils of beryllium mounted on a tantalum backing. Eastman NTA 100 micron emulsions were mounted 4 inches away at angles of 0, 45, and 90 degrees. The first exposure was made with a bombarding energy of 3.817 Mev. The data plotted in 50 keV intervals and corrected for variation of $n-p$ scattering cross section is shown in Fig. 1 and Fig. 2. Because of the large uncertainty in the determination of the angle of recoil for tracks from low energy particles, 0.4 Mev was arbitrarily set as the lower limit of measurements. Applying the criteria for acceptance of tracks becomes increasingly difficult below 1.0 Mev, so that the actual uncertainty in the region between 0.4 and 1.0 Mev is somewhat greater than the indicated statistical uncertainty.

The data show clearly the group from the transition to the ground state of B^9 . Below this there occurs a continuous energy distribution of neutrons. Comparison with the earlier $Li(p,n)$ data¹ under similar conditions indicates that this continuous distribution does not result from background neutrons and scattering. The low intensity of the continuum in the region between 0.4 and 1.0 Mev on the 90° plate also excludes the possibility of the intensity in this region on the 0 and 45 degree plates from being due to an isotropic background in the room. To check the results of the first experiment a somewhat different target arrangement was

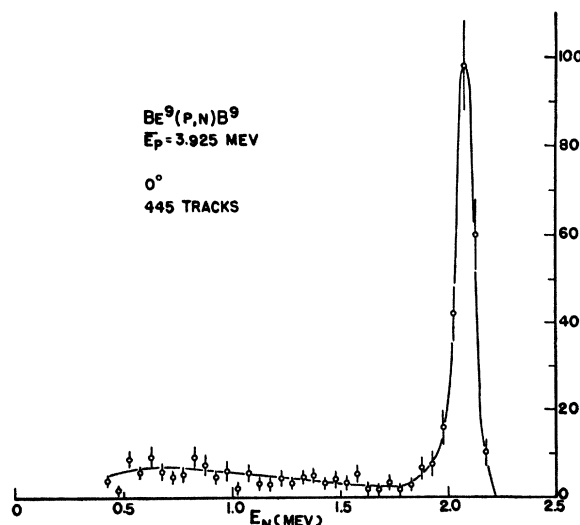


FIG. 3. Number of neutrons per 50 keV interval versus neutron energy for $\bar{E}_p = 3.925$ Mev at 0° .

constructed and a second exposure was made. The bombarding energy was 3.940 Mev. The 0 degree data are shown in Fig. 3.

Several possible origins of the continuum were considered. Cascade processes, in which the 2.41 Mev excited state² of Be^9 is formed and subsequently breaks up into either Be^8 and a neutron or into He^8 and He^4 , are not able to give the observed data. The continuum could arise from the break-up of the compound nucleus either into Be^8 , a proton, and a neutron, or into Be^8 and a deuteron in the singlet state. Another quite different possibility is that the continuum results from the interaction of the incident proton chiefly with the very loosely bound neutron in Be^9 without the formation of a compound state. The relatively low intensity of the continuum on the 90 degree plates might favor this possibility. Finally, one cannot rule out the possibility of the existence of a very broad level in B^9 .

In regard to the use of the $Be^9(p,n)$ reaction as a neutron source, it is of interest to note that the thin target neutron yield versus energy curve does not show an observable yield of neutrons for proton bombarding energies between the (p, pn) threshold and the (p, n) threshold.⁵ If the continuum is due to the (p, pn) reaction, one can probably expect the yield of the continuum to remain at a low value throughout a useful range of energies.

We wish to extend our sincere appreciation to Professor H. T. Richards, who suggested this problem and with whom we have had many invaluable discussions.

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¹ Johnson, Laubenstein, and Richards, Phys. Rev. **77**, 413 (1950).

² B. Hammermesh and V. Hummel, Phys. Rev. **78**, 73 (1950).

³ K. E. Davis and E. M. Hafner, Phys. Rev. **73**, 1473 (1948).

⁴ E. Guth and C. J. Mullin, Phys. Rev. **74**, 833 (1948).

⁵ Browne, Smith, and Richards, Phys. Rev. **77**, 754 (1950).

Masses of Si^{30} , Co^{59} , Ni^{60} , Zr^{90} , Mo^{96} and Mo^{100} *

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THE mass spectrographic mass determinations recently reported have been extended to include Si^{30} , Ni^{60} , Zr^{90} , Mo^{96} and Mo^{100} . From the mass of Ni^{60} that of Co^{59} can be deduced, using disintegration data.

Si^{30} , Ni^{60} and Co^{59} . With an ion source consisting of a spark between two silicon electrodes, photographs were taken of the CH_3-Si^{30} doublet appearing at mass number 15. From eight photographs, the CH_3-Si^{30} packing fraction difference¹ was found to be $\Delta f = 24.53 \pm 0.05$. Assuming the packing fraction of CH_3 to be 18.83 ± 0.015 , that of Si^{30} is found to be -5.70 ± 0.05 . This is in satisfactory agreement with the value -5.64 ± 0.02 listed by Mattauch and Flammersfeld,³ and by Alburger and Hafner.⁴

The $Si^{30}-Ni^{60}$ packing fraction difference has been found in this laboratory⁵ to be $\Delta f = 2.90 \pm 0.01$. This, when combined with the above value for Si^{30} , gives for Ni^{60} , $f = -8.60 \pm 0.05$. This is in satisfactory agreement with Shaw's⁶ value of -8.69 ± 0.08 , but does not agree very well with the value of -8.37 ± 0.06 obtained by Okuda *et al.*⁷

The packing fraction of Co^{59} can be computed from Ni^{60} by use of the Q -value for the $Co^{59}(d, p)Co^{60}$ reaction, recently measured by Bateson and Pollard.⁸ Their Q of 5.19 Mev, together with values of 0.308 Mev and 2.40 Mev for the beta- and gamma-rays from Co^{60} , as listed by Mattauch and Flammersfeld,³ gives a packing fraction for Co^{59} of $f = -8.43$. In this computation, Bainbridge's recommended values² for the masses of H^1 and H^2 were used.

Zr^{90} . With a spark between a silicon and a zirconium electrode, the $Si^{30}-Zr^{90}$ doublet was photographed at mass 30. The packing fraction difference was found from five photographs to be $\Delta f = 1.88 \pm 0.04$. This, combined with the above Si^{30} value, gives the packing fraction of Zr^{90} as $f = -7.58 \pm 0.07$.

Mo⁹⁶ and Mo¹⁰⁰. With a spark between two molybdenum electrodes, the C₂-Mo⁹⁶ and C₂H-Mo¹⁰⁰ doublets were photographed at mass numbers 24 and 25. From eleven photographs, the C₂-Mo⁹⁶ packing fraction difference was found to be $\Delta f = 9.88 \pm 0.03$. From seventeen photographs of the C₂H-Mo¹⁰⁰ doublet, $\Delta f = 12.47 \pm 0.03$. Assuming the packing fractions of C₂ and C₂H to be 3.213 ± 0.016 and 6.336 ± 0.016 , respectively, that of Mo⁹⁶ is found to be $f = -6.67 \pm 0.04$ and that of Mo¹⁰⁰ $f = -6.14 \pm 0.04$.

Table I gives the new mass values found in this work.

TABLE I. New mass values.

Nuclide	Packing fraction	Mass
Si ⁸⁰	-5.70 ± 0.05	29.98290 ± 0.00015
Co ⁵⁹	-8.43	58.95029
Ni ⁶⁰	-8.60 ± 0.05	59.94840 ± 0.00030
Zr ⁹⁰	-7.58 ± 0.07	89.93178 ± 0.00063
Mo ⁹⁶	-6.67 ± 0.04	95.93597 ± 0.00039
Mo ¹⁰⁰	-6.14 ± 0.04	99.93860 ± 0.00040

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** On leave from Bates College.

¹ The factor $\times 10^{-4}$ will be understood and not written in expressing the numerical value of the packing fraction.

² K. T. Bainbridge, *Isotopic Weights of the Fundamental Isotopes*, Preliminary Report No. 1, National Research Council, June, 1948.

³ J. Mattauch and A. Flammersfeld, "Isotopic Report—1948," Verlag d. Zeits. f. Natur., Tübingen, Germany, 1949.

⁴ D. E. Alburger and E. M. Hafner, *The Properties of Atomic Nuclei—III*, Nuclear Energy Levels, Z=11-20 (Brookhaven National Laboratory, July 1, 1949).

⁵ Duckworth, Johnson, Preston, and Woodcock, *Phys. Rev.* **78**, 386 (1950).

⁶ A. E. Shaw, *Phys. Rev.* **75**, 1011 (1949).

⁷ Okuda, Ogata, Kuroda, Sima, and Shindo, *Phys. Rev.* **59**, 104 (1941).

⁸ W. O. Bateson and E. Pollard, *Phys. Rev.* (to be published).

The Microwave Rotational Spectrum and Structure of Bromogermane

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WE have measured and identified about one hundred lines arising from the fourth, fifth, and sixth pure rotational transitions of Ge⁷⁰, Ge⁷², Ge⁷⁴, and Ge⁷⁶ in the eight possible combinations with Br⁷⁹ and Br⁸¹ in GaH₃Br. In addition, the dipole moment of SiH₃Br has been determined to be 1.31 ± 0.03 Debye units. The measured and derived constants for GeH₃Br are listed in Table I. Although the absolute accuracy of the quoted frequencies is about ± 1 Mc/sec, the isotopic frequency differences were measured considerably more accurately (± 0.1 Mc/sec).

TABLE I. Molecular constants for GeH₃Br.

Species (Ge and Br mass numbers)	Frequencies ± 1 (Mc/sec.) <i>J</i> = 4-5	<i>B</i> ₀ average (Mc/sec.)
70-79	24385.54	2438.57
70-81	24101.61	2410.17
72-79	24064.35	2406.42
72-81	23780.11	2378.01
74-79	23758.99	2375.88
74-81	23474.75	2347.46
76-79	23468.0	2346.84
76-81	23183.8	2318.37

Within the allowable experimental error, the *B*₀ values computed from the different transition frequencies for a given isotopic species may be considered constant, as they should be if the centrifugal distortion correction is negligible.

The theoretical hyperfine structure to be expected for a nuclear spin of $\frac{3}{2}$ for bromine was found to be in excellent agreement with the observed spectra, indicating zero spin for the even isotopes of Ge. Lines due to Ge⁷²H₃Br⁷⁹ and Ge⁷²H₃Br⁸¹ were observed in the predicted positions. As was expected, they had very complex structure because of the further splitting due to the quadrupole coupling of the Ge⁷³ nucleus found by Townes *et al.*¹ in GeH₃Cl. The quadrupole coupling constants $eQ(\partial^2 V/\partial z^2)$ were determined from measurements involving the *J* = 3→4 transition where the pattern was least complicated.

The dipole moment of SiH₃Br was determined by analysis of the movement of Stark components of the *J* = 2→3, *K* = 2, *F* = 7/2 → (5/2, 7/2, 9/2) line. Because of experimental and theoretical difficulties the dipole moment of GeH₃Br is not available at this time.

The structure of this molecule was determined using the average moments of inertia obtained for the three transitions of Ge⁷⁰H₃Br⁷⁹, Ge⁷⁰H₃Br⁸¹, and Ge⁷⁴H₃Br⁸¹ and checked against the remaining species. Since accurate values of the isotopic masses of germanium have not been measured, these were computed using a packing fraction² of -6.7×10^{-4} mass unit. The structural data and quadrupole coupling constants for this molecule are compared with the corresponding quantities for CH₃Br and SiH₃Br in Table II. Although not stated explicitly, the limits of error on the

TABLE II. Structural parameters for CH₃Br, SiH₃Br, and GeH₃Br.

Molecule	CH ₃ Br ^a	SiH ₃ Br ^b	GeH ₃ Br
X-Br(A)	1.932 (1.93)	2.209 ± 0.001 (2.31)	2.297 ± 0.001 (2.36)
H-X(A)	1.11 (1.09)	1.57 ± 0.03 (1.47)	1.55 ± 0.05 (1.52)
H-X-H	109°22'	111°20' ± 1°	112°0' ± 1°
Dipole moment (Debye)	1.797 ^c	1.31 ± 0.03	
	<i>eQ</i> (∂ ² <i>V</i> /∂ <i>z</i> ²)(Mc/sec.)		
Br ⁷⁹	577	336	380
Br ⁸¹	482	278	321

^a Gilliam, Edwards, and Gordy, *Phys. Rev.* **75**, 1014 (1949).

^b Sharbaugh, Bragg, Madison, and Thomas, *Phys. Rev.* **76**, 1419 (1949).

^c Shulman, Townes, and Dailey, *Phys. Rev.* **78**, 145 (1950).

CH₃Br structural parameters are of the same order, or slightly greater, than those quoted for the other two molecules, since the CH₃Br structure determination was based partially on less accurate infra-red data. The numbers in parentheses are the sums of the covalent radii of the respective atoms. Within the limits of experimental error, the angle $\angle HXH$ must be considered to be the same for these three molecules and very nearly tetrahedral (109°28').

As in the corresponding series of chlorides³ there is a marked shortening of the Si-Br and Ge-Br bonds. This is attributed to contributions from a double bond structure of the sort H₃Si⁻Br⁺ involving use of a *d*-orbital which is not available in carbon. On the basis of quadrupole coupling constants⁴ and bond shortening one can make the following semiquantitative assignment of bond characters: CH₃Br, 18 percent ionic; SiH₃Br, 40 percent ionic, 25 percent double bond; GeH₃Br, 40 percent ionic, 15 percent double bond.

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¹ Townes, Mays and Dailey, *Phys. Rev.* **76**, 700 (1949).

² J. Mattauch, *Nuclear Physics Table* (Interscience Publishers, Inc., New York, 1940), p. 113.

³ Dailey, Mays, and Townes, *Phys. Rev.* **76**, 136 (1949).

⁴ C. H. Townes and B. P. Dailey, *J. Chem. Phys.* **17**, 782 (1949).