Letters to the Editor

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Distribution in Mass and Charge of Fission Products*

K. H. KINGDON
General Electric Knolls Atomic Power Laboratory, Schenectady, New York
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IT is not well understood why the fission products are divided into two distinct mass groups separated by a marked minimum. This note makes a suggestion concerning this problem.

When a nucleus of U^{235} picks up a slow neutron it may become so distorted that ultimately it separates into two major fragments. It is reasonable to assume that this fission will occur in such a way as to produce fragments having the greatest ability to bind the excess neutrons which were present in the parent distorted nucleus. The ability of a nucleus to bind neutrons may be measured by $(A-Z)/Z$, so that isotopes of stable elements having particularly high values of $(A-Z)/Z$ may be expected to be prominent among the fission products. This hypothesis affords no criterion of the possibility of fission, but merely attempts to tell what the fragments will be if fission does occur.

A tabulation was made of values of $(A-Z)/Z$ for elements with Z lying between 10 and 80. The mass numbers used were the average mass numbers taken from Mattauch's *Nuclear Physics Tables*, and thus account was taken of the relative abundance of the various isotopes. These data are plotted in Fig. 1 (circles for even Z and crosses for odd), and it is seen that the values of $(A-Z)/Z$ for odd Z in the central region lie systematically below the values for even Z, corresponding to the systematic difference between even and odd nuclei. This difference is much more marked if the plot is made for stable isotopes of maximum A for each Z. According to the above hypothesis it would be expected therefore that all the initial fission products would be of even Z. This may well be the case, because it is probable that many of the initial fission products have not been listed yet on account of their short half-lives. Assuming then that the initial fission products are all of even Z, the probabilities of forming various pairs of initial products may be found by taking pairs of complementary values of Z, $(Z_1+Z_2=92)$, and adding together the corresponding values of $(A-Z)/Z$. These values are plotted in Fig. 2. A similar curve for initial fragments of odd Z is shown dotted in Fig. 2, and it is clear that fragments of odd Z are less likely to be formed than those of even Z in the central region of the figure. The scale of ordinates in Fig. 2 is presumably approximately exponential as regards percentages of the various fragments formed.

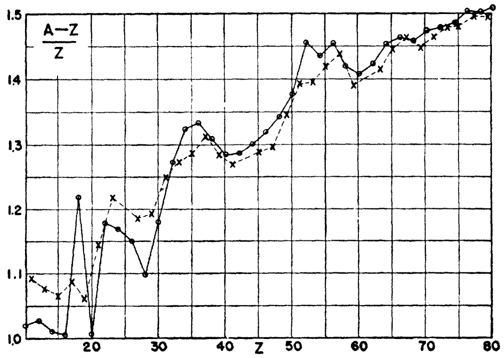

FIG. 1. Plot of $(A-Z)/Z$ as a function of Z. The circles are for even Z; crosses for odd Z.

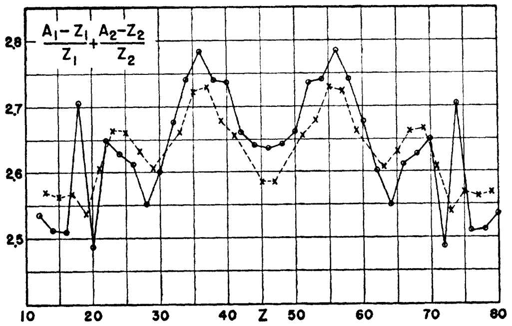

FIG. 2. Plot of $(A_1-Z_1)/Z_1+(A_2-Z_2)/Z_2$ as a function of Z, where Z_1+Z_2 equals 92.

The central part of the curve of Fig. 2 is strikingly similar to the well-known[1] curve showing percentage of fission products as a function of mass number. The change of abscissa from Z to A and the formation of various isotopes may well change the shape of Fig. 2 to that shown in the A curve.

The location of Fig. 2 on the Z axis is in reasonable agreement with the A curve. Figure 2 shows the central minimum at $Z=46$, which matches the minimum at 117 of the A curve fairly well. On the two wings of the A curve, abundances equal to the central minimum are reached at $A=77$ and 157, while on Fig. 2 the corresponding values of Z are about 32 and 60, in fair correspondence.

Figure 2 departs from the mass number curve of reference 1 in suggesting an appreciable possibility of fission into a very light and a very heavy fragment, especially for argon and tungsten.

The occurrence of the deep minimum in Fig. 2 implies that the incipient fission fragments have time to sort themselves out into the most stable possible pairs. If the fission act occurs so rapidly that complete "sorting" is not possible, the central minimum will be higher. This is presumably the cause of the less deep central minimum in fission by fast neutrons.

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* Based on Knolls Atomic Power Laboratory Report A-4271 dated September 8, 1947.

[1] J. Am. Chem. Soc. **68**, 2411 (1946), see p. 2437.

Microwave Rotational Spectra and Structures of GeH_3Cl, SiH_3Cl, and CH_3Cl*

B. P. DAILEY, J. M. MAYS, AND C. H. TOWNES
Columbia University, New York, New York
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PURE rotational spectra due to the $J=2\rightarrow3$ transition of all ten isotopic combinations of Ge^{70}, Ge^{72}, Ge^{73}, Ge^{74}, Ge^{76}, and Cl^{35} and Cl^{37} in GeH_3Cl have been observed. In addition, previously unreported lines corresponding to the $J=1\rightarrow2$ transition of the rarer isotopic species of chlorosilane, $Si^{29}H_3Cl^{35}$, $Si^{29}H_3Cl^{37}$, and $Si^{30}H_3Cl^{35}$ and the $J=0\rightarrow1$ transition of $C^{13}H_3Cl^{35}$ and $C^{13}H_3Cl^{37}$ have been found. Rotational constants obtained from those lines that have been measured accurately are contained in Table I.

TABLE I. Rotational constants for XH_3Cl molecules.

Molecule	B_0 (mc/sec.)
$C^{12}H_3Cl^{35}$	13,292.89[a]
$C^{12}H_3Cl^{37}$	13,088.19[a]
$C^{13}H_3Cl^{35}$	12,796.2
$C^{13}H_3Cl^{37}$	12,590.0
$Si^{28}H_3Cl^{35}$	6673.8[b]
$Si^{28}H_3Cl^{37}$	6512.4[b]
$Si^{30}H_3Cl^{35}$	6485.8
$Ge^{70}H_3Cl^{35}$	4401.71
$Ge^{74}H_3Cl^{35}$	4333.91
$Ge^{74}H_3Cl^{37}$	4177.90
$Ge^{76}H_3Cl^{37}$	4146.5

[a] See reference 1.
[b] See reference 2.

The new data obtained combined with those of Gordy *et al.*[1] and Sharbaugh[2] allow the molecular structures of methyl chloride, chlorosilane, and chlorogermane to be determined completely using only accurate microwave measurements. The structural parameters obtained are assembled in Table II. The structures of CH_3Cl and SiH_3Cl differ to some extent from earlier values based partially on infra-red data and on the Si—H distance in silane. The new H—Si—H angle is 110°57′ instead of 103°57′, which is a less drastic change from the tetrahedral angle (109°28′) and in close agreement with corresponding angles in CH_3Cl and GeH_3Cl. No corrections for the effect of zero-point vibration on bond distance and angles have been made. Maximum errors which zero-point vibrations are likely to produce are 0.01A in the X—H distance, 0.003A in the X—Cl distance, and 30′ in the H×H angle.

Hyperfine structure due to the chlorine nuclei is present in GeH_3Cl. The quadrupole coupling constant for Cl^{37} in this molecule is given in Table II.

Dipole moments of SiH_3Cl and GeH_3Cl have been obtained by measurement of Stark displacement as a function of field strength and are also listed in Table II.

The shortening of the Si—Cl and Ge—Cl bonds, the considerably smaller Cl quadrupole coupling in SiH_3Cl and GeH_3Cl than in CH_3Cl, as well as the irregular progression of dipole moments indicate clearly that the Si and Ge compounds involve importantly some electronic structure which does not occur in CH_3Cl. This structure is very probably of the type $H_3Si^{-}=Cl^{+}$, involving use of a *d* orbital to form five Si bonds and a doubly bonded Cl. The *d* orbitals are of course not available in C. The occurence of structures of this type in molecules involving the heavier elements has been discussed by Pauling[3] and suggested by Gilliam *et al.*[4] as an explanation for the small SiH_3Cl dipole moment and the H—Si—H angle of 103°57′ reported by Sharbaugh.[2]

A rather satisfactory semiquantitative correlation of the data of Table II can in fact be obtained by assigning 20 percent ionic character to the C—Cl bond, 40 percent ionic and 30 percent double bond character to the Si—Cl bond, and 45 percent ionic and 15 percent double bond character to the Ge—Cl bond. These numbers fit the quadrupole coupling constants,[5] X—Cl distances, and dipole moments, as well as agreeing with the general principles of dependence of ionic character on electronegatively differences and the tendency for the lighter elements to form double bonds more easily than their heavier congeners.

TABLE II. Structural data for XH_3Cl Molecules.

Molecule	CH_3Cl	SiH_3Cl	GeH_3Cl
Dipole moment (Debye units)			
Microwave value	1.88[a]	1.31	2.13
Previous value	1.86	1.28[c]	2.03[e]
X-Cl distance (angstroms)			
Measured value	1.781	2.048	2.147
Sum of single bond radii	1.76	2.16	2.21
H —X distance (angstroms)			
Measured value	1.12	1.50	1.52
Sum of single bonded radii	1.07	1.47	1.52
HXH angle	110°50′	110°57′	111°4′
Quadrupole coupling const. *eqQ* for Cl^{37} (mc/sec.)	−59.03[b]	−30[d]	−34

[a] R. Karplus and A. H. Sharbaugh, Phys. Rev. **75**, 1449 (1949); R. G. Shulman, private communication.
[b] See reference 1.
[c] L. O. Brockway and I. E. Coop, Trans. Faraday Soc. **34**, 1429 (1938).
[d] See reference 2.
[e] Smyth, Grossman, and Ginsburg, J. Am. Chem. Soc. **62**, 192 (1940).

Hyperfine structure caused by a Ge^{73} nuclear quadrupole coupling in the molecule GeH_3Cl has been observed. Although this hyperfine structure is not yet completely analyzed, it is clear that the quadrupole coupling constant is large. This is very good evidence for ionic character of the Ge—Cl bond, since other electronic structures suggested for this bond would give only a very small quadrupole coupling to the germanium nucleus.

Studies of other halogen derivatives of silane and germanium as well as further examination of possible hyperfine structure due to Ge and Si nuclei are being undertaken.

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[*] Work supported jointly by the Signal Corps and the ONR.
[1] W. Gordy, J. W. Simmons, and A. G. Smith, Phys. Rev. **74**, 243 (1948).
[2] A. H. Sharbaugh, Phys. Rev. **74**, 1870 (1948).
[3] L. C. Pauling, *The Nature of the Chemical Bond* (Cornell University Press, Ithaca, New York, 1940), second edition, p. 228.
[4] O. R. Gilliam, H. D. Edwards, and W. Gordy, Phys. Rev. **75**, 1014 (1949).
[5] Cf. C. H. Townes and B. P. Dailey, J. Chem. Phys. to be published.

Ferromagnetic Resonance Absorption Magnetite*

L. R. Bickford, Jr.
Laboratory for Insulation Research, Massachusetts Institute of Technology, Cambridge, Massachusetts
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THE previously reported[1] results of ferromagnetic resonance absorption experiments on natural single crystals of magnetite have been substantially confirmed with synthetic single crystals in both the 3 cm and 1 cm wave-length regions.

The experiments were made with thin circular disks cut from the (100) crystal plane. For the purpose of calculating demagnetizing effects, they were regarded as oblate spheroids. The disks, one side of which had been copper-plated, were soldered to a rotatable portion of the wall of a rectangular resonant cavity. This allowed a change in the orientation of the crystal axes with respect to the applied d.c. magnetic field. From two measurements of the resonance magnetic field, one with the [100] and the other with the [110] crystal direction parallel to the field, one can calculate the first order anisotropy constant K_1 and the *g*-factor by means of Kittel's equations.[2] In order to allow measurements to be made at low temperatures, the cavity was thermally insulated from the rest of the wave-guide system.

Table I gives typical experimental results. Figure 1 shows values of *g* and K_1 calculated from these results. These values are esti-

TABLE I. Experimental results for synthetic magnetite single crystal.

Temperature (°C)	Saturation magnetization (c.g.s.)	Resonance field (gauss) [100]	Resonance field (gauss) [110]	Frequency (mc/sec.)	*g* factor	K_1 (ergs/cc)
	Sample diameter: 0.1246″; thickness: 0.0036″					
+20	461	1775	980	8923	2.17	$--1.12\times10^5$
−143	492	1330	1330	8945	2.08	0
−153	494	1200	1450	8946	2.06	$+3.65\times10^4$
	Sample diameter: 0.0705″; thickness: 0.0030″					
+20	461	6300	5680	23957	2.13	-1.11×10^5
−143	492	5850	5850	23986	2.09	0