

547.246: 543.51

## MASS SPECTRA OF SOME TETRA-ALKYLGERMANIUM COMPOUNDS

BY

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This paper reports the monoisotopic mass spectra of the compounds  $\text{Ge}(\text{Alkyl})_4$ , in which Alkyl = methyl, ethyl, propyl, butyl, pentyl and hexyl. With the aid of metastable ion transitions the fragmentation patterns could be given. With the exception of  $\text{GeMe}_4$  these are all similar and can be explained by a few rules, the first being the tervalence of the Ge after primary ionization. In  $\text{GeMe}_4$  splitting off of alkene fragments is difficult. As the alkyl chain length increases hydrocarbon ion abundance increases considerably.

### Introduction

1. One of the conclusions of a preceding paper on the mass spectra of the tetramethyl- and tetraethyl-compounds of carbon, silicon, germanium, tin and lead <sup>1</sup> was that the fragmentation always leaves the electron deficiency on the metal-containing fragment, as might be expected from the respective electronegativities of carbon and the metals.

After removal of an electron from one of the molecular orbitals charge rearrangement in the primary ion is fast compared with the time required for fragmentation <sup>2</sup>. The result is that the electron configuration of the metal now is that of a trivalent element and that, accordingly, a neutral alkyl fragment is always split off first.

It seemed worth while to see whether this behaviour persists when the alkyl chains are longer; the fragmentation patterns of the compounds  $\text{Ge}(\text{Alkyl})_4$ , in which Alkyl =  $\text{CH}_3$ ,  $\text{C}_2\text{H}_5$ ,  $\text{C}_3\text{H}_7$ ,  $\text{C}_4\text{H}_9$ ,  $\text{C}_5\text{H}_{11}$  and  $\text{C}_6\text{H}_{13}$  were therefore investigated.

### Experimental

2. The mass spectra were recorded on an A.E.I. MS 9 spectrometer under the following conditions:

Electron accelerating voltage 70 V

Pressure  $\pm 1.3 \times 10^{-6}$  mm Hg

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<sup>1</sup> J. J. de Ridder and G. Dijkstra, *Rec. Trav. Chim.* **86**, 737 (1967).

<sup>2</sup> A. L. Wahrhaftig in "Mass Spectrometry", (R. I. Reed, ed.) Academic Press, London 1965, p. 137.

Ionizing current            100  $\mu$ A  
 Temperature                230  $\pm$  5  $^{\circ}$ C.

The monoisotopic spectra have been calculated using the method described by *Dibeler*<sup>3</sup>. The metal organic compounds were kindly supplied by the Organisch Chemisch Instituut T.N.O., Utrecht, where investigations in this field sponsored by the Germanium Research Committee, are being carried out.

The metastable ion transitions  $m_1^+ \rightarrow m_2^+ + m_3$ , have been determined either by measurement of  $m^*$  in the spectra, or by the method described by *Jennings*<sup>4</sup>.

When using this last method, the mass spectrometer is modified in such a way, that the ratio of accelerating voltage V to analyser voltage E can be varied continuously between 0.5 and 2.0 times the normal value. The ions of mass  $m_2^+$ , formed by the reaction mentioned above, after acceleration, but before entering the electrostatic analyser, are transmitted if V/E is altered by a factor of  $m_1/m_2$ .

This ratio determines uniquely the metastable ion transition. Using this method metastable peaks corresponding to almost every ion transition can be found and the fragmentation pattern traced.

## Results and discussion

### 3.1 Description of the spectra

The calculated monoisotopic spectra are given in Table I. The intensities are given in percentages of total ionization and have been corrected for the abundance of <sup>13</sup>C. Metastable and doubly charged ions, like peaks with intensities smaller than 0.25% have been omitted.

Table I  
 Monoisotopic mass spectra of tetra-alkylgermanium compounds

Ion	Ge(Me) <sub>4</sub>	Ge(Et) <sub>4</sub>	Ge(Pr) <sub>4</sub>	Ge(Bu) <sub>4</sub>	Ge(Pent) <sub>4</sub>	Ge(Hex) <sub>4</sub>
CH <sub>3</sub>	0.35					
C <sub>2</sub> H <sub>2</sub>		0.31		0.33	0.33	0.28
C <sub>2</sub> H <sub>3</sub>	0.36	0.76	1.64	1.38	1.69	1.33
C <sub>2</sub> H <sub>4</sub>		0.55		0.61	0.52	0.52
C <sub>2</sub> H <sub>5</sub>		0.49		3.71	2.04	2.05
C <sub>3</sub> H <sub>3</sub>			0.91	0.67	0.80	0.81
C <sub>3</sub> H <sub>5</sub>	0.52		1.84	2.22	3.05	2.87
C <sub>3</sub> H <sub>6</sub>			0.46		0.98	0.88
C <sub>3</sub> H <sub>7</sub>	0.30		0.85		3.36	3.62
C <sub>4</sub> H <sub>7</sub>				4.10	1.01	2.55
C <sub>4</sub> H <sub>8</sub>	0.39			0.30	0.25	0.89
C <sub>4</sub> H <sub>9</sub>				0.64		0.48
C <sub>5</sub> H <sub>9</sub>					4.96	0.45
C <sub>5</sub> H <sub>10</sub>					0.26	
C <sub>5</sub> H <sub>11</sub>					0.26	
C <sub>6</sub> H <sub>9</sub>						0.28

<sup>3</sup> V. H. Dibeler and F. L. Mohler, J. Res. Natl. Bur. Standards **47**, 337 (1951).

<sup>4</sup> K. R. Jennings, J. Chem. Phys. **43**, 4175 (1965).

Table I (Continued)

Monoisotopic mass spectra of tetra-alkylgermanium compounds

Ion	Ge(Me) <sub>4</sub>	Ge(Et) <sub>4</sub>	Ge(Pr) <sub>4</sub>	Ge(Bu) <sub>4</sub>	Ge(Pent) <sub>4</sub>	Ge(Hex) <sub>4</sub>
C <sub>6</sub> H <sub>11</sub>						3.65
C <sub>6</sub> H <sub>12</sub>						0.54
Ge	1.55	1.47	1.42	1.05	0.61	0.28
GeH	2.77	2.92	1.17	0.86	0.53	0.26
GeH <sub>3</sub>		1.91	1.47	0.67	0.46	0.31
GeCH	0.30				0.30	
GeCH <sub>2</sub>	1.64	0.26				
GeCH <sub>3</sub>	8.03	0.63	3.88	3.28	2.39	0.83
GeCH <sub>4</sub>			0.59			
GeCH <sub>5</sub>	2.92	0.41	5.22	2.95	1.16	1.92
GeC <sub>2</sub> H	0.47	0.29				
GeC <sub>2</sub> H <sub>3</sub>	0.31	0.71		0.63	0.72	0.25
GeC <sub>2</sub> H <sub>4</sub>				0.31		
GeC <sub>2</sub> H <sub>5</sub>	0.47	4.56	1.07	2.36	3.34	2.31
GeC <sub>2</sub> H <sub>6</sub>	3.54	0.73				
GeC <sub>2</sub> H <sub>7</sub>	0.90	14.96		1.67	1.75	3.41
GeC <sub>3</sub> H <sub>5</sub>			0.45	0.35	0.61	0.26
GeC <sub>3</sub> H <sub>6</sub>			0.64		0.47	0.26
GeC <sub>3</sub> H <sub>7</sub>			1.43		0.71	0.72
GeC <sub>3</sub> H <sub>8</sub>			1.00			
GeC <sub>3</sub> H <sub>9</sub>	71.1		13.27		1.70	1.19
GeC <sub>4</sub> H <sub>7</sub>				0.40		0.31
GeC <sub>4</sub> H <sub>8</sub>				0.60		
GeC <sub>4</sub> H <sub>9</sub>		0.33		1.09	0.51	1.38
GeC <sub>4</sub> H <sub>10</sub>		0.92		0.92		
GeC <sub>4</sub> H <sub>11</sub>		35.88		19.06		1.05
GeC <sub>5</sub> H <sub>9</sub>					0.28	
GeC <sub>5</sub> H <sub>10</sub>					0.40	
GeC <sub>5</sub> H <sub>11</sub>					1.48	0.41
GeC <sub>5</sub> H <sub>12</sub>					0.75	
GeC <sub>5</sub> H <sub>13</sub>					20.75	
GeC <sub>6</sub> H <sub>11</sub>						0.27
GeC <sub>6</sub> H <sub>14</sub>			0.64			0.66
GeC <sub>6</sub> H <sub>15</sub>		26.60	39.32			19.17
GeC <sub>8</sub> H <sub>18</sub>				0.32		
GeC <sub>8</sub> H <sub>19</sub>				31.10	0.64	
GeC <sub>8</sub> H <sub>20</sub>		1.41				
GeC <sub>9</sub> H <sub>13</sub>						0.93
GeC <sub>9</sub> H <sub>15</sub>						0.27
GeC <sub>9</sub> H <sub>21</sub>			20.44			
GeC <sub>10</sub> H <sub>21</sub>					0.37	
GeC <sub>10</sub> H <sub>23</sub>					26.87	
GeC <sub>12</sub> H <sub>25</sub>						0.45
GeC <sub>12</sub> H <sub>27</sub>				14.65	0.29	24.16
GeC <sub>15</sub> H <sub>33</sub>					9.09	
GeC <sub>18</sub> H <sub>39</sub>						11.56

The metastable ion transitions are given for the most abundant isotope ( $^{74}\text{Ge}$ ) in Table II. Only metastable peaks down to  $M^* = 12$  have been taken into account.

Table II

Metastable ion transitions of the tetra-alkylgermanium compounds, based on  $\text{Ge} = 74$

Compound	$M^*$	$M_1 \rightarrow M_2$	Reaction
GeMe <sub>4</sub>	69.59	119 → 91	$\text{GeC}_3\text{H}_9^+ \rightarrow \text{GeCH}_5^+ + \text{C}_2\text{H}_4$
	87.04	91 → 89	$\text{GeCH}_5^+ \rightarrow \text{GeCH}_3^+ + \text{H}_2$
	87.01	89 → 88	$\text{GeCH}_3^+ \rightarrow \text{GeCH}_2^+ + \text{H}$
	90.9	119 → 104	$\text{GeC}_3\text{H}_9^+ \rightarrow \text{GeC}_2\text{H}_6^+ + \text{CH}_3$
GeEt <sub>4</sub>	136.43	190 → 161	$\text{GeC}_8\text{H}_{20}^+ \rightarrow \text{GeC}_6\text{H}_{15}^+ + \text{C}_2\text{H}_5$
	109.87	161 → 133	$\text{GeC}_6\text{H}_{15}^+ \rightarrow \text{GeC}_4\text{H}_{11}^+ + \text{C}_2\text{H}_4$
	82.89	133 → 105	$\text{GeC}_4\text{H}_{11}^+ \rightarrow \text{GeC}_2\text{H}_7^+ + \text{C}_2\text{H}_4$
	101.04	105 → 103	$\text{GeC}_2\text{H}_7^+ \rightarrow \text{GeC}_2\text{H}_5^+ + \text{H}_2$
	54.61	103 → 75	$\text{GeC}_2\text{H}_5^+ \rightarrow \text{GeH}^+ + \text{C}_2\text{H}_4$
GePr <sub>4</sub>	167.60	246 → 203	$\text{GeC}_{12}\text{H}_{28}^+ \rightarrow \text{GeC}_9\text{H}_{21}^+ + \text{C}_3\text{H}_7$
	127.72	203 → 161	$\text{GeC}_9\text{H}_{21}^+ \rightarrow \text{GeC}_6\text{H}_{15}^+ + \text{C}_3\text{H}_6$
	126.17	203 → 160	$\text{GeC}_9\text{H}_{21}^+ \rightarrow \text{GeC}_6\text{H}_{14}^+ + \text{C}_3\text{H}_7$
	86.14 •	161 → 119	$\text{GeC}_6\text{H}_{15}^+ \rightarrow \text{GeC}_3\text{H}_9^+ + \text{C}_3\text{H}_6$
	69.53	119 → 91	$\text{GeC}_3\text{H}_9^+ \rightarrow \text{GeCH}_5^+ + \text{C}_2\text{H}_4$
GeBu <sub>4</sub>	198.80	302 → 245	$\text{GeC}_{16}\text{H}_{36}^+ \rightarrow \text{GeC}_{12}\text{H}_{27}^+ + \text{C}_4\text{H}_9$
	145.80	245 → 189	$\text{GeC}_{12}\text{H}_{27}^+ \rightarrow \text{GeC}_8\text{H}_{19}^+ + \text{C}_4\text{H}_8$
	93.57	189 → 133	$\text{GeC}_8\text{H}_{19}^+ \rightarrow \text{GeC}_4\text{H}_{11}^+ + \text{C}_4\text{H}_8$
	182.78	133 → 105	$\text{GeC}_4\text{H}_{11}^+ \rightarrow \text{GeC}_2\text{H}_7^+ + \text{C}_2\text{H}_4$
	62.21	133 → 91	$\text{GeC}_4\text{H}_{11}^+ \rightarrow \text{GeCH}_5^+ + \text{C}_3\text{H}_6$
	129.00	133 → 131	$\text{GeC}_4\text{H}_{11}^+ \rightarrow \text{GeC}_4\text{H}_9^+ + \text{H}_2$
GePent <sub>4</sub>	164.0	287 → 217	$\text{GeC}_{15}\text{H}_{33}^+ \rightarrow \text{GeC}_{10}\text{H}_{23}^+ + \text{C}_5\text{H}_{10}$
	99.6	217 → 147	$\text{GeC}_{10}\text{H}_{23}^+ \rightarrow \text{GeC}_5\text{H}_{13}^+ + \text{C}_5\text{H}_{10}$
	94.3	145 → 117	$\text{GeC}_5\text{H}_{11}^+ \rightarrow \text{GeC}_3\text{H}_7^+ + \text{C}_2\text{H}_4$
	56.26	147 → 91	$\text{GeC}_5\text{H}_{13}^+ \rightarrow \text{GeCH}_5^+ + \text{C}_4\text{H}_8$
	73.22 *	147 → 105	$\text{GeC}_5\text{H}_{13}^+ \rightarrow \text{GeC}_2\text{H}_7^+ + \text{C}_3\text{H}_6$
	32.83	145 → 69	$\text{GeC}_5\text{H}_{11}^+ \rightarrow \text{C}_5\text{H}_9^+ + \text{GeH}_2$

• This apparent mass corresponds with transitions of the  $^{72}\text{Ge}$  isotope.

Table II (Continued)

Metastable ion transitions of the tetra-alkylgermanium compounds, based on Ge = 74

Compound	M *	M <sub>1</sub> → M <sub>2</sub>	Reaction
GeHex <sub>4</sub>	182.45	329 → 245	GeC <sub>18</sub> H <sub>39</sub> <sup>+</sup> → GeC <sub>12</sub> H <sub>27</sub> <sup>+</sup> + C <sub>6</sub> H <sub>12</sub>
	157.0	161 → 159	GeC <sub>6</sub> H <sub>15</sub> <sup>+</sup> → GeC <sub>6</sub> H <sub>13</sub> <sup>+</sup> + H <sub>2</sub>
	109.9	161 → 133	GeC <sub>6</sub> H <sub>15</sub> <sup>+</sup> → GeC <sub>4</sub> H <sub>11</sub> <sup>+</sup> + C <sub>2</sub> H <sub>4</sub>
	105.78	245 → 161	GeC <sub>12</sub> H <sub>27</sub> <sup>+</sup> → GeC <sub>6</sub> H <sub>15</sub> <sup>+</sup> + C <sub>6</sub> H <sub>12</sub>
	88.0	161 → 119	GeC <sub>6</sub> H <sub>15</sub> <sup>+</sup> → GeC <sub>3</sub> H <sub>9</sub> <sup>+</sup> + C <sub>3</sub> H <sub>6</sub>
	86.09	159 → 117	GeC <sub>6</sub> H <sub>13</sub> → GeC <sub>3</sub> H <sub>7</sub> <sup>+</sup> + C <sub>3</sub> H <sub>6</sub>
	69.60	119 → 91	GeC <sub>3</sub> H <sub>9</sub> <sup>+</sup> → GeCH <sub>5</sub> <sup>+</sup> + C <sub>2</sub> H <sub>4</sub>
	68.43	159 → 103	GeC <sub>6</sub> H <sub>13</sub> <sup>+</sup> → GeC <sub>2</sub> H <sub>5</sub> <sup>+</sup> + C <sub>4</sub> H <sub>8</sub>
	68.43	161 → 105	GeC <sub>6</sub> H <sub>15</sub> <sup>+</sup> → GeC <sub>2</sub> H <sub>7</sub> <sup>+</sup> + C <sub>4</sub> H <sub>8</sub>
	67.70	117 → 89	GeC <sub>3</sub> H <sub>7</sub> <sup>+</sup> → GeCH <sub>3</sub> <sup>+</sup> + C <sub>2</sub> H <sub>4</sub>
	42.87	161 → 83	GeC <sub>6</sub> H <sub>15</sub> <sup>+</sup> → C <sub>6</sub> H <sub>11</sub> <sup>+</sup> + GeH <sub>4</sub>
	43.32	159 → 83	GeC <sub>6</sub> H <sub>13</sub> <sup>+</sup> → C <sub>6</sub> H <sub>11</sub> <sup>+</sup> + GeH <sub>2</sub>

Considering the spectra, a typical difference between the spectra of tetramethyl germanium and the other tetra-alkylgermanium compounds may be observed. While in the spectrum of tetramethylgermanium the base peak is formed by the ion Ge(CH<sub>3</sub>)<sub>3</sub><sup>+</sup>, the other compounds show a base peak corresponding to the ion H Ge(Alkyl)<sub>2</sub><sup>+</sup>. In the spectrum of tetramethylgermanium the latter peak is insignificant. The cause of this difference will be pointed out in 3.2.

Further general characteristics of the spectra are:

1. The near absence of the molecular ion peak.
2. The near absence of germanium-containing ions due to carbon-carbon bond fission, except those with the ions (H<sub>2</sub>Ge Alkyl)<sup>+</sup> or (Ge Alkyl)<sup>+</sup> as origin.

Trends observable with increasing number of carbon atoms in the alkyl group:

3. The amount of the ions Ge(Alkyl)<sub>3</sub><sup>+</sup> decreases.
4. The amount of the ions H Ge(Alkyl)<sub>2</sub><sup>+</sup> increases, passes a maximum in tetrapropylgermanium and decreases again.
5. The abundance of (H<sub>2</sub>Ge Alkyl)<sup>+</sup> ions increases somewhat.
6. The total amount of germanium-containing carbon-carbon bond fission products increases.
7. The total amount of germanium ions and germanium hydride ions decreases.
8. The total amount of hydrocarbon fragment ions increases.



element in the periodic table (Ga) which is a stable configuration <sup>1</sup>. Except in the spectrum of tetramethylgermanium, further fragmentation occurs by successive elimination of stable entities, like the molecules (Alkyl-H), resulting in the stable three-coordinated configurations  $\{H\ Ge(Alkyl)_2\}^+$ ,  $(H_2\ Ge\ Alkyl)^+$  and  $(H_3Ge)^+$ .

Starting from the ions  $(H_2Ge\ Alkyl)^+$ , two reaction paths are possible, elimination of hydrogen or elimination of a molecule (Alkyl-H).

The guiding principle appears to be that fragmentation takes place in such a way that the bond fission products can assume a stable configuration.

This will be the case when:

i. The metal-containing fragment ion is an even-electron system <sup>5</sup>, in which the germanium is in the tervalent state.

ii. The neutral carbon hydrogen fragment is an even-electron molecule such as an alkene, or molecular hydrogen.

Reactions governed by these principles can occur only in tetraethyl- up to tetrahexyl-germanium. In tetramethylgermanium, these reactions meet with difficulties. For one thing alkene elimination occurs only if there is a possibility of interaction between two methyl groups. This will hardly be the case in tetramethylgermanium with the result that it occurs only to a very small extent. Methyl radical elimination from the trimethyl-germanium ion is not favoured because it would leave the germanium in the unstable odd electron, bivalent configuration. A twofold methyl radical elimination does occur, because the product ion formed by this reaction is an even-electron system and the germanium is in the monovalent state, which is the most stable one next to the tervalent state.

### 3.3. The carbon-hydrogen ion abundance

The ratios of the total amount of carbon-hydrogen ions to germanium containing ions have been calculated and are presented in Table III.

Table III

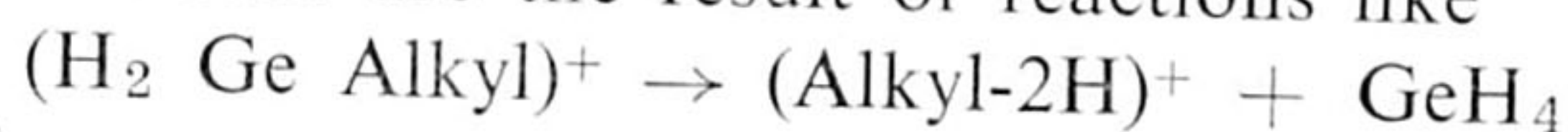
The ratios of total amount carbon-hydrogen ions to germanium containing ions

Compound	$\Sigma CH/\Sigma GeCH$
GeMe <sub>4</sub>	0.035
GeEt <sub>4</sub>	0.030
GePr <sub>4</sub>	0.074
GeBu <sub>4</sub>	0.180
GePent <sub>4</sub>	0.283
GeHex <sub>4</sub>	0.305

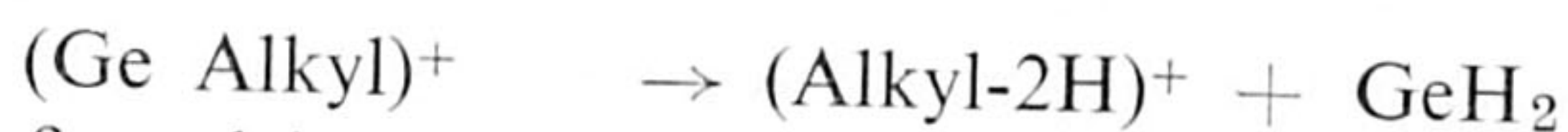
<sup>5</sup> R. I. Reed, Ion Production by Electron Impact, Academic Press, London and New York 1962, p. 158.

The relative abundance of carbon-hydrogen ions decreases from tetramethylgermanium to tetraethylgermanium. This may be explained by the fact that in tetraethylgermanium the highly favoured ethylene elimination is possible, this in contrast with the tetramethyl compound.

From tetraethyl- up to tetrahexyl-germanium, the relative abundance of carbon-hydrogen ions increases, but more than could be expected by the increase of total number of carbon atoms. (Such would be the case if the simple assumption were made that electron deficiency is distributed evenly over C—C bonds of similar surroundings<sup>6</sup>). The number of carbon atoms increases by a factor of 3, while the abundance of carbon hydrogen ions, relative to the total amount of germanium-containing ions increases by a factor of 10. From the spectra it may be seen that the greatest contribution to the total amount of carbon-hydrogen ions is caused by the ions (Alkyl-2H)<sup>+</sup>. These ions are the result of reactions like



and



as could be confirmed by strong metastable peaks in the spectra of tetrapentyl- and tetrahexyl-germanium. In the spectra of the tetramethyl- up to the tetrabutyl compounds, these metastable peaks could not be observed. The method of *Jennings*, described in § 2 could not be used here, because we are not yet able to vary the ratio V/E by a factor of more than 2. However, we may expect that the ions (Alkyl-2H)<sup>+</sup> in the spectra of all investigated germanium compounds are the result of the reactions mentioned above.

In agreement with the rules given in 3.2, the germanium in the neutral metal hydride fragments is either in the stable tetravalent state, or in the bivalent state.

#### 3.4. Carbon-carbon bond fission products

As was shown already, carbon-carbon bond fission only takes place in the mono- and di-alkylgermanium fragment ions. If we define a relative fragmentation index *F* as the number of ionized fragments produced by breaking a given bond, divided by the mean per bond of the total number of ionized fragments formed by breaking metal-carbon or carbon-carbon bonds, we have in this a measure of the percentage of fission occurring at the given bond relative to the *a priori* percentage were the fissions to occur completely at random<sup>7</sup>.

<sup>6</sup> G. R. Lester, Brit. J. Appl. Phys. **14**, 414 (1963).

<sup>7</sup> F. H. Field and J. L. Franklin, Electron Impact Phenomena and the Properties of Gaseous Ions, Academic Press, New York 1957, p. 169.



Fig. 1 shows the calculated relative fragmentation indices for the monoalkylgermanium ions, while the indices for the dialkylgermanium ions are shown in Fig. 2.

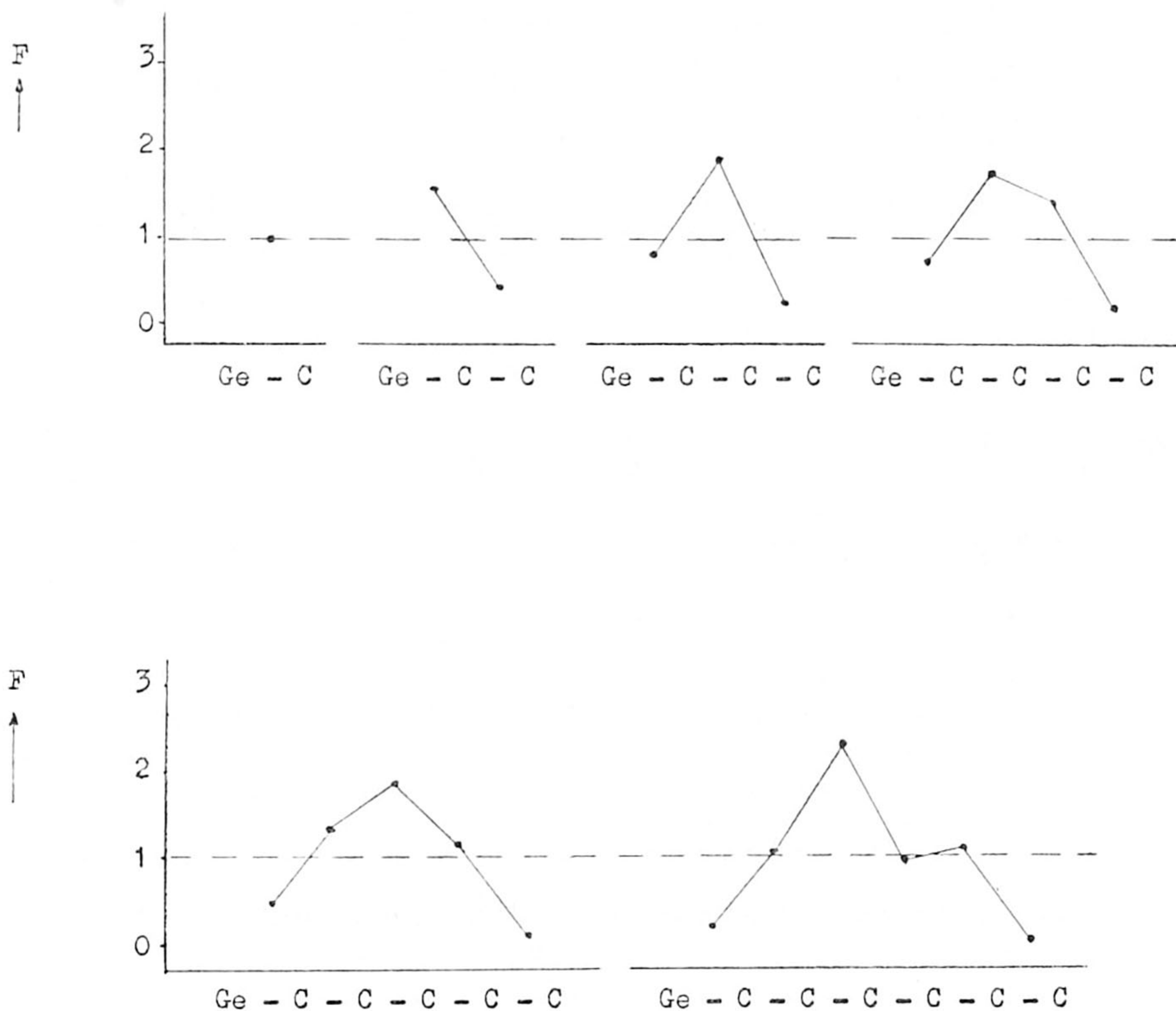


Fig. 1. Relative fragmentation indices of the monoalkylgermanium ions

These figures denote that the dialkylgermanium ions preponderantly fragmentate by elimination of an alkyl group. In the dialkylgermanium ions, therefore, the germanium-carbon bonds seem to be weaker than the carbon-carbon bonds. The monoalkylgermanium ions on the contrary show a fragmentation of the alkyl chain. In these ions, the chance of a germanium-carbon bond fission decreases with increasing number of carbon atoms. The fragmentation of the monoalkylgermanium ions takes place in such a way, that the result is in general an ion of the form Ge-C or Ge-C-C, keeping in mind that the monopentyl- and monohexyl-germanium ions prefer ions of the form Ge-C-C, while in the other compounds the ions Ge-C are the most abundant.

Although a treatment of these molecules by the method of *Lester*<sup>6</sup> would be rewarding, the presence of the hetero atom complicates the calculations to such an extent that the results become uncertain.

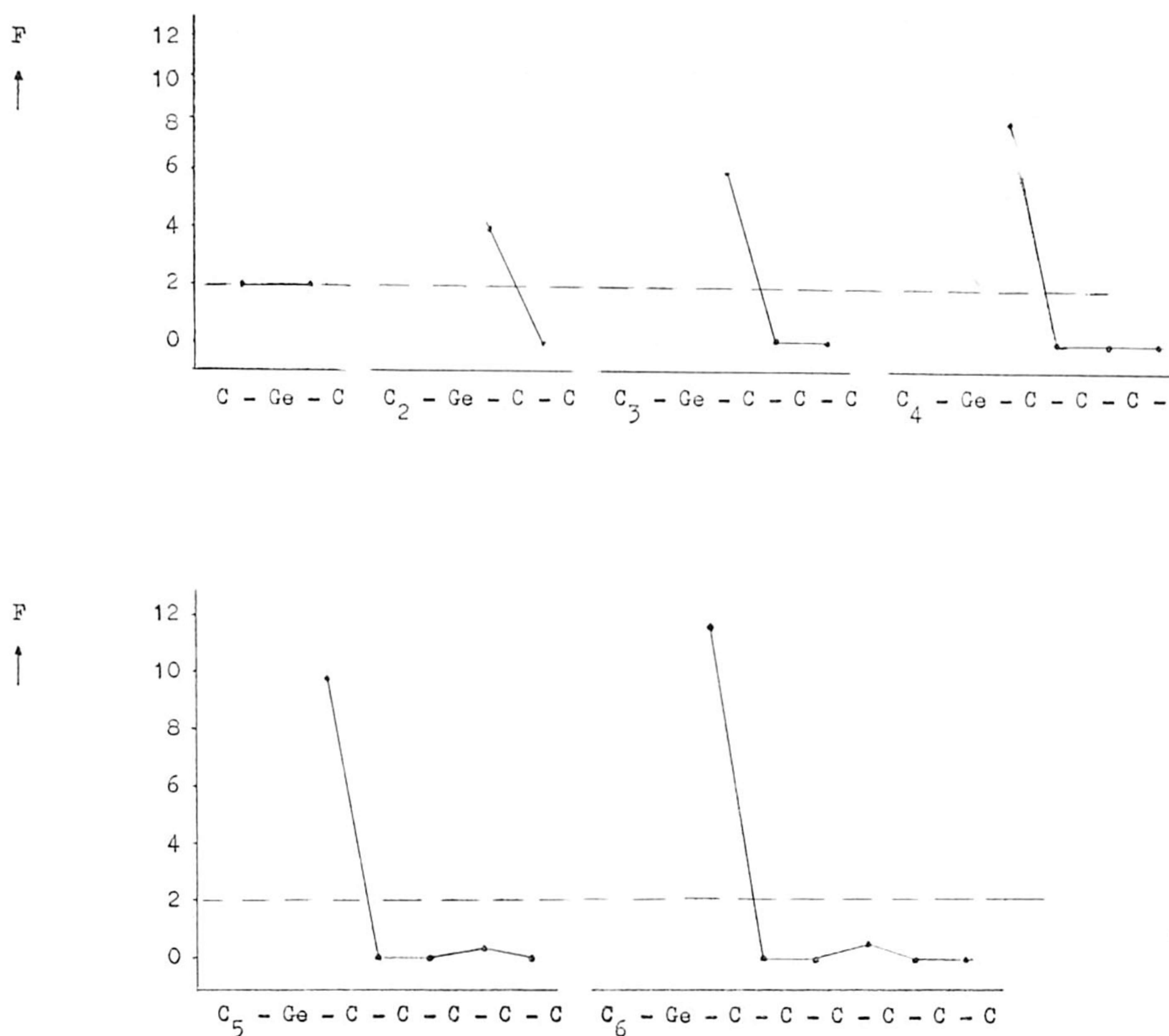


Fig. 2. Relative fragmentation indices of the dialkylgermanium ions

### Conclusions

1. The fragmentation patterns of the tetra-propyl-, -butyl-, -pentyl-, and -hexyl-germanium compounds are roughly similar to that of tetra-ethylgermanium, reported in <sup>1</sup>.

2. The conclusion that the ionization and primary fragmentation of the germanium tetra-alkyls leaves the electron deficiency on the metal-containing fragments is valid for alkyl chains up to C<sub>6</sub>.

3. The occurrence of carbon-carbon bond fissions increases with increasing number of carbon atoms with preference for ions of the form Ge-C or Ge-C-C.

4. In secondary fragmentation processes, hydrocarbon ions are formed increasingly as the chain length increases.

The germanium in the neutral fragments is then tetravalent or divalent.

(Received August 8th. 1967).