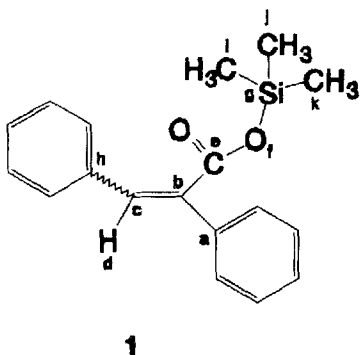


## JMS Letters

Dear Sir,

**Rearrangement Reactions of  $\alpha$ -Phenylcinnamic Acid Trimethylsilyl Esters Upon Electron Impact Ionization: Practical and Theoretical Aspects\***

The Perkin condensation of benzaldehyde and phenylacetic acid in the presence of triethylamine gives an isomeric mixture of  $\alpha$ -phenylcinnamic acids.<sup>1</sup> The isomeric ratio can be influenced by the choice of solvent, reaction time and temperature of reflux.<sup>2</sup> Accurate composition can be determined by gas chromatography/mass spectrometry (GC/MS) after derivatization, i.e., through the determination of the trimethylsilyl or the tert-butyldimethylsilyl derivatives of the acids.<sup>2</sup> Upon electron impact (EI) ionization, several secondary transformations may proceed in the mass spectrometer, such as fragmentation and rearrangement reactions.<sup>3</sup> Identification of most fragments is usually straightforward and the sensitivity of routine GC/MS equipment is adequate, but rationalization of the rearrangement reactions may require more sophisticated high-resolution instrumentation.



In the mass spectra taken by GC/MS from the trimethylsilyl esters of  $\alpha$ -phenylcinnamic acid isomers, three peaks indicating rearrangement reactions were found [ $m/z$  135, 152 and 237, each with appreciable intensities (8.5–21.6%)].<sup>4</sup> Although mechanisms leading to these fragments were offered in the cited paper, it turned out to be unrealistic for the lower fragments. Clearly, further investigation at high resolution was needed. Results of these measurements are given in this paper. In addition, a computational method is presented that has proved to be successful in predicting major fragmentation pathways.

Synthesis of the pure  $\alpha$ -phenylcinnamic acid isomers was based on the method of Fieser.<sup>5</sup> It involved heating a mixture of benzaldehyde (2 ml), phenylacetic acid (2.5 g), acetic anhydride (2 ml) and triethylamine (2 ml). On varying the duration of reflux, the isomeric composition varied. To obtain reasonable amounts of both isomers, reflux for 35 min was needed. For derivatization the silylating agent *N,N*-diethyltrimethylsilylamine (Fluka) was used. Samples of the pure isomers (10 mg) were dissolved in *N,N*-dimethylformamide (100  $\mu$ l) and excess silylating agent (500  $\mu$ l) was added at room temperature. The reaction was complete within 5 min. A 5  $\mu$ l volume of this mixture was used for GC/MS analysis. The crystalline form of the silylated E isomer was used for high-resolution measurements.

For the GC/MS analysis, a Hewlett-Packard Model 5890 gas chromatograph equipped with a quadrupole mass-

selective detector was applied. Data analysis was performed on an HP 5997 Chemstation attached to the apparatus. A 50 m HP1 capillary column was used; the solvent delay was 7 min, and a temperature program was applied from 523 to 623 K with a ramp of 4 K min<sup>-1</sup>. The electron energy was 70 eV. High-resolution mass spectrometric measurements were performed on crystalline samples on a Finnigan MAT 8430 mass spectrometer. The operating conditions were as follows: electron energy, 70 eV; electron current, 50  $\mu$ A; ion acceleration voltage, 3 kV; and temperature of ion source, 523 K. In high resolution ( $R = 10\,000$ ) mass measurements, perfluorokerosene (PFK) was used as the reference standard.

To explore bond strengths in the isomers, semi-empirical quantum chemical calculations were carried out with the AM1 method, included in the Pcmol package.<sup>6</sup> Full geometric optimization was performed for the neutral molecules and the molecular ions of the isomers of the trimethylsilyl esters 1 (*E*, the ester and the  $\beta$ -phenyl groups are on opposite sides; *Z*, the ester and the  $\beta$ -phenyl groups are on the same side of the olefinic double bond). Bond orders were taken as a measure of bond strength. They were calculated for the optimized geometries and compared for the isomer pair.

The mass-selective detector of the GC/MS instrument was used for initial mass spectrometric investigation. It turned out that the fragmentation pathways were the same for the two isomers, only the abundances of the fragment ions were different. The major fragments could be identified easily (Table 1). They were formed via the scission of the O–Si, Si–C and C–O bonds, or decarboxylation occurring with the subsequent loss of the olefinic hydrogen. These last two processes were the most important fragmentation pathways. Basic fragmentation routes could be predicted by the semi-empirical (AM1) quantum chemical method. Bond order calculations on the geometrically optimized molecular ion revealed that the O–Si bond was the weakest and the Si–CH<sub>3</sub> and the olefinic(C)–C(ester) bonds were easy to cleave (Table 2).

A significant bond order decrease in the olefinic double bond (b–c) on going from the AM1-optimized neutral molecule to that of the radical cation showed that the molecular ion was formed *via* the removal of an electron from the olefinic  $\pi$ -bond. This ion was involved in theoretically predicted

**Table 1. The most abundant fragment ions, their  $m/z$  values and relative peak intensities in the EI mass spectra of (*E*)- and (*Z*)- $\alpha$ -phenylcinnamic acid trimethylsilyl ester isomers 1**

Fragment	$m/z$	Relative intensity (%)	
		<i>E</i>	<i>Z</i>
M <sup>+</sup>	296	78.2	48.6
[M – CH <sub>3</sub> ] <sup>+</sup>	281	64.1	43.2
2 <sup>a</sup>	237	11.5	8.1
[M – OSi(CH <sub>3</sub> ) <sub>3</sub> ] <sup>+</sup>	207	16.7	9.5
[M – CO <sub>2</sub> Si(CH <sub>3</sub> ) <sub>3</sub> ] <sup>+</sup>	179	100.0	100.0
[M – Si(CH <sub>3</sub> ) <sub>3</sub> OH – CO] <sup>+</sup>	178	82.1	81.1
3 <sup>b</sup>	152	15.4	12.2
4 <sup>b</sup>	135	20.5	21.6
[(CH <sub>3</sub> ) <sub>3</sub> SiO] <sup>+</sup>	89	5.1	8.1
[(CH <sub>3</sub> ) <sub>2</sub> SiOH] <sup>+</sup>	75	19.2	24.3
[(CH <sub>3</sub> ) <sub>3</sub> Si] <sup>+</sup>	73	70.5	100.0
[SiOH] <sup>+</sup>	45	20.5	33.8

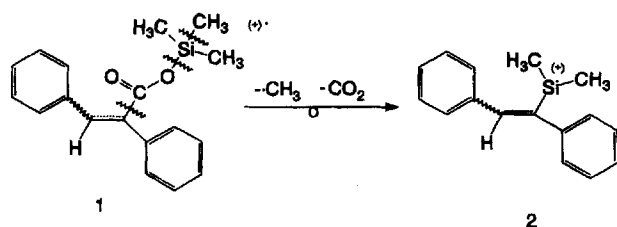
<sup>a</sup> See Scheme 1.

<sup>b</sup> See Scheme 2.

\* The work was presented at the 13th International Mass Spectrometry Conference, Budapest, Hungary (poster: Mo C12).

**Table 2.** Bond orders in the molecular ions (roman type) and the natural molecules (italics) of the trimethylsilyl ester derivatives of stereoisomeric  $\alpha$ -phenylcinnamic acids **1**, determined for geometries optimized by AM1 semi-empirical quantum chemical method

Bond	<i>E</i>	<b>1</b>	
		<i>E</i>	<i>Z</i>
a-b	1.14	0.99	1.15
b-c	1.45	1.82	1.44
b-e	0.94	0.94	0.94
c-d	0.93	0.94	0.93
c-h	1.20	1.02	1.20
e-f	1.04	1.12	1.04
f-g	0.67	0.65	0.67
g-i	0.88	0.87	0.88
g-j	0.88	0.88	0.88
g-k	0.91	0.88	0.91

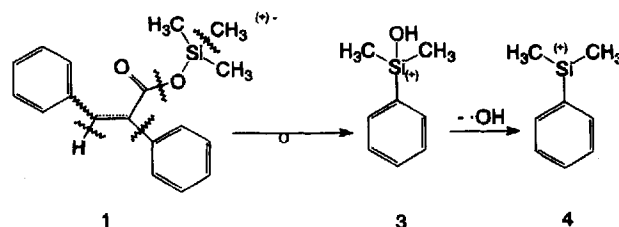


**Scheme 1.** Route to fragment of  $m/z$  237 (**2**).

and experimentally found fragmentation reactions and gave rise to various rearrangements reported in this paper.

As indicated in a recent paper,<sup>3</sup> rearrangement reactions could take place upon EI of  $\alpha$ -phenylcinnamic acid esters resulting in the formation of benzopyrilium ions. We also identified the relevant species ( $m/z$  295), however, this rearrangement pathway was of minor importance. Here, the very labile O—Si bond was not cleaved. In most other fragmentation reactions of these compounds, the O—Si bonds were cleaved preferentially ( $m/z$  207). The high relative intensities of the peaks at  $m/z$  281 and 179 indicated that Si—CH<sub>3</sub> and C(olefinic)—C(ester) bond scissions were also facile.

High-resolution mass spectrometry revealed that fragments of  $m/z$  135, 152 and 237 all contained Si. Isotopic satellites of  $m/z$  137, 154 and 239 disappeared in the background of the mass spectra. However, they became clearly identifiable by high-resolution mass spectrometry. This observation can be interpreted by rearrangement reactions: after O—Si and Si—CH<sub>3</sub> bond scissions, the Si-containing moieties migrated to other parts of the molecule. Migration was accompanied by CO<sub>2</sub> elimination in the case of the fragment of  $m/z$  237 and a



**Scheme 2.** Route to fragments of  $m/z$  152 (**3**) and 135 (**4**).

C(olefinic)—Si bond was formed in place of the C(olefinic)—C(ester) bond (Scheme 1).

A fragment of  $m/z$  152 was formed similarly, except that the target of migration was a detached phenyl group and a dimethylphenylsilanol ion was produced. The loss of OH transformed  $m/z$  152 into  $m/z$  135 (Scheme 2).

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Yours,

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