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Gas Chromatography/Electron Impact Mass Spectrometry Applied to the Differentiation of the Positional Isomers of Long-chain *n*-Alkylcyclohexanones

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The influence of *n*-butyl group position upon the fragmentation behavior of the three isomeric *n*-butylcyclohexanones was studied. The different fragmentation processes are described and have been applied to the differentiation of the positional isomers of long-chain *n*-alkylcyclohexanones. In the case of the 4-*n*-alkyl isomers, an interesting mechanism involving a recyclization is proposed and substantiated by deuterium labelling.

INTRODUCTION

We have previously studied the photosensitized oxidation of *n*-alkylcyclohexanes.[1] Among the different photoproducts identified we gave evidence of the formation of isomeric *n*-alkylcyclohexanones. During the identification of these compounds involving comparison of their mass spectra with those of synthetized standards, we observed some interesting fragmentations which permit a relatively easy differentiation of the positional isomers and particularly of 3-*n*-alkylcyclohexanones and 4-*n*-alkylcyclohexanones.

In the present work, we thus studied more precisely these fragmentations in the case of 2-*n*-butylcyclohexanone, 3-*n*-butylcyclohexanone and 4-*n*-butylcyclohexanone. Then, we attempted to apply these fragmentations to the differentiation of the three isomeric *n*-dodecylcyclohexanones, in order to generalize the application of the fragmentation mechanisms to the whole family of long-chain *n*-alkylcyclohexanones.

EXPERIMENTAL

The different *n*-alkylcyclohexanones used were obtained by photosensitized oxidation of the corresponding *n*-alkylcyclohexanes in the presence of traces of anthraquinone.[1]

The synthesis of 2,2,6,6-d_4-4-*n*-butylcyclohexanone required five steps.

(i) Condensation of 1,4-cyclohexanedione monoethylene-acetal (0.027 mole) with *n*-butyl magnesium bromide (0.03 mole) which gave an 80% yield of hydroxy-acetal.
(ii) Dehydration (overnight) of the hydroxy-acetal in toluene catalysed by *para*-toluene-sulphonic acid (yield: 70%).
(iii) Hydrogenation (110 bars, overnight) of the foregoing alkene-acetals in methanol with Raney nickel catalyst (yield: 85%).
(iv) Quantitative hydrolysis of the foregoing acetal to the corresponding ketone.[2]
(v) Deuterium exchange of the hydrogen atoms adjacent to the carbonyl group.[3]

A Ribermag R.10.10.C spectrometer was used coupled with a D.I.700 gas chromatograph. The following operating conditions were employed: column: CP-Sil 5 (50 m × 0.32 mm i.d.); carrier gas: helium (pressure 0.9 bar); temperature programmed from 90 to 200 °C at 3 °C/min, then from 200 to 300 °C at 8 °C/min; electron energy: 70 eV; and source temperature: 120 °C.

RESULTS AND DISCUSSION

During the GC/MS analysis, the three isomeric *n*-butylcyclohexanones were easily separated and gave definite molecular peaks at *m*/*z* 154 (Figs 1, 2 and 3).

The mass spectrum of 2-*n*-butylcyclohexanone (Fig. 1) can be easily differentiated from the two other isomers by its base peak at *m*/*z* 98 arising from a classical β-cleavage with transfer of a γ-hydrogen atom,[4,5] which is only possible in the case of 2-*n*-alkylcyclohexanones with a chain length of two or more carbon atoms.

In the case of the 3-*n*-butylcyclohexanone (Fig. 2), the cleavage ① results in the formation of the fragment ion *b* (*m*/*z* 97). After the α-cleavages ② and ③ of the molecular ion *a* leading to the formation of *d* and *h*, subsequent hydrogen radical transfers and homolytic bond ruptures[6] yield fragment ions at *m*/*z* 55 (*f*), *m*/*z* 97 (*j*) and *m*/*z* 111 (*l*). The fragment *l* corresponding to $[M-43]^+$ is characteristic of this isomer (independently of the length of the alkyl chain).

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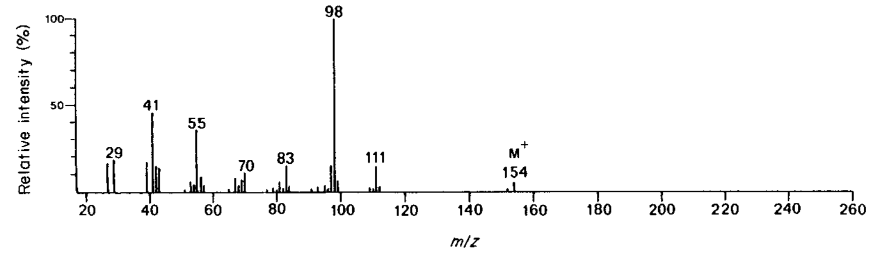

Figure 1. Electron impact mass spectrum of 2-*n*-butylcyclohexanone.

The mass spectrum of 4-*n*-butylcyclohexanone (Fig. 3) is more complex and also more interesting. As with the previous isomer, it presents an intense peak at *m/z* 97 (*b*) (cleavage ①). The primary radical ion *d* arising from α-cleavage ② can undergo two hydrogen radical transfers[7] which lead to the formation of two secondary radical sites (*e* and *f*). Homolytic bond ruptures of these radical ions give fragments at *m/z* 55 (*o*) and *m/z* 139 (*h*). In order to explain the formation of fragments of considerable intensity at *m/z* 126 and *m/z* 125, we propose the mechanisms described in Fig. 3 involving a cyclization of the radical ion *e*. The molecular ion of the 2,4-diethylcyclohexanone (*i*) thus formed can either lose the 4-ethyl chain and lead to the fragment ion at *m/z* 125 (*m*), or undergo a β-cleavage with transfer of a γ-hydrogen atom of the 2-ethyl chain (*j* → *l*) leading to the formation of the fragment ion at *m/z* 126 (*l*). This β-cleavage will only be possible in the case of 4-*n*-alkylcyclohexanones with a chain length of four or more carbon atoms.

The formation of the fragment ions at *m/z* 139, *m/z* 125 and *m/z* 126 according to the proposed mechanisms is supported by the shift of these peaks respectively to *m/z* 143, *m/z* 127 and *m/z* 130, respectively, on the mass spectrum of the 2,2,6,6-d_4-4-*n*-butylcyclohexanone (Fig. 4).

It follows from this GC/MS analysis of the *n*-butylcyclohexanone isomers that 2-*n*-alkylcyclohexanones (with a chain length of two or more carbon atoms) can be characterized unambiguously owing to their base peak at *m/z* 98.[4,5] The differentiation of the two other isomers can be made by the peak at $[M-43]^+$ for 3-*n*-alkylcyclohexanones and by the peaks at $[M-29]^+$, *m/z* 139 and *m/z* 126 for 4-*n*-alkylcyclohexanones (with a chain length of four or more carbon atoms).

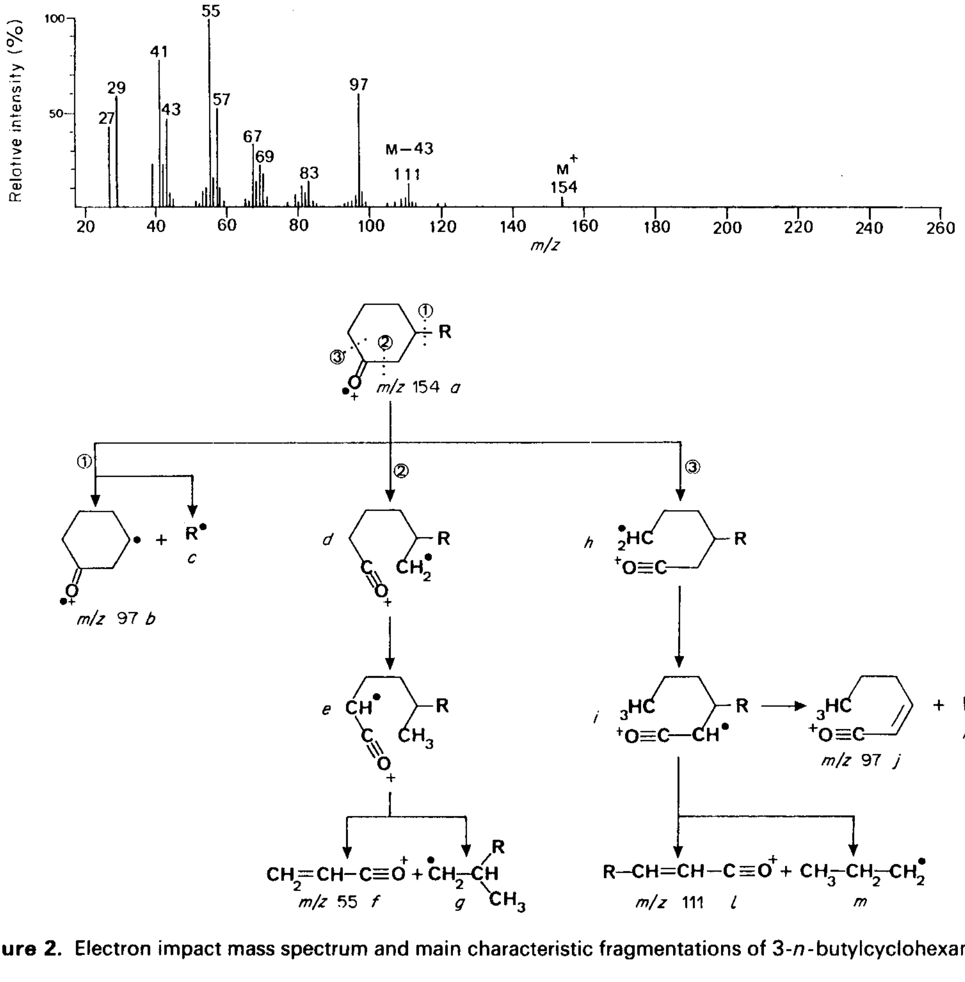

Figure 2. Electron impact mass spectrum and main characteristic fragmentations of 3-*n*-butylcyclohexanone.

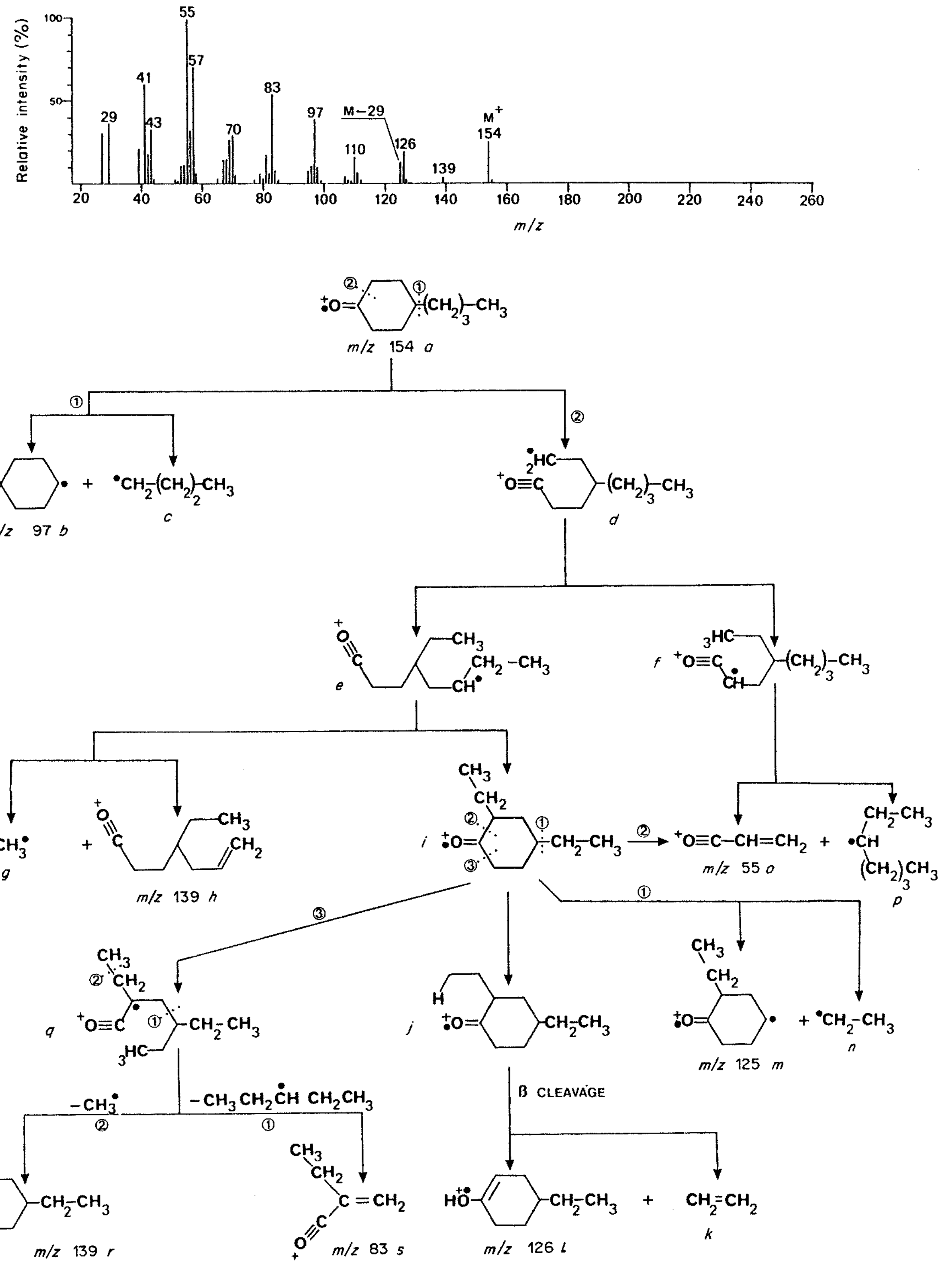

Figure 3. Electron impact mass spectrum and proposed characteristic fragmentations of 4-*n*-butylcyclohexanone.

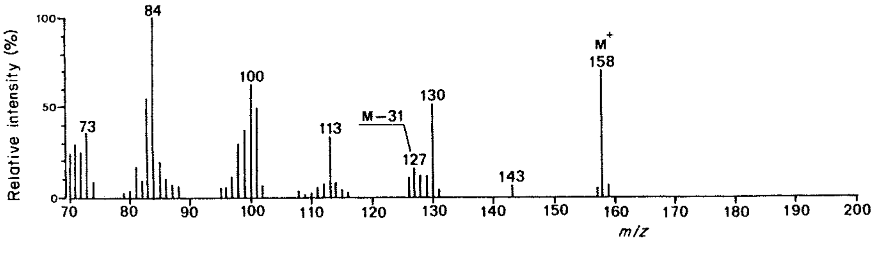

Figure 4. Electron impact mass spectrum of 2,2,6,6-d_4-4-*n*-butylcyclohexanone.

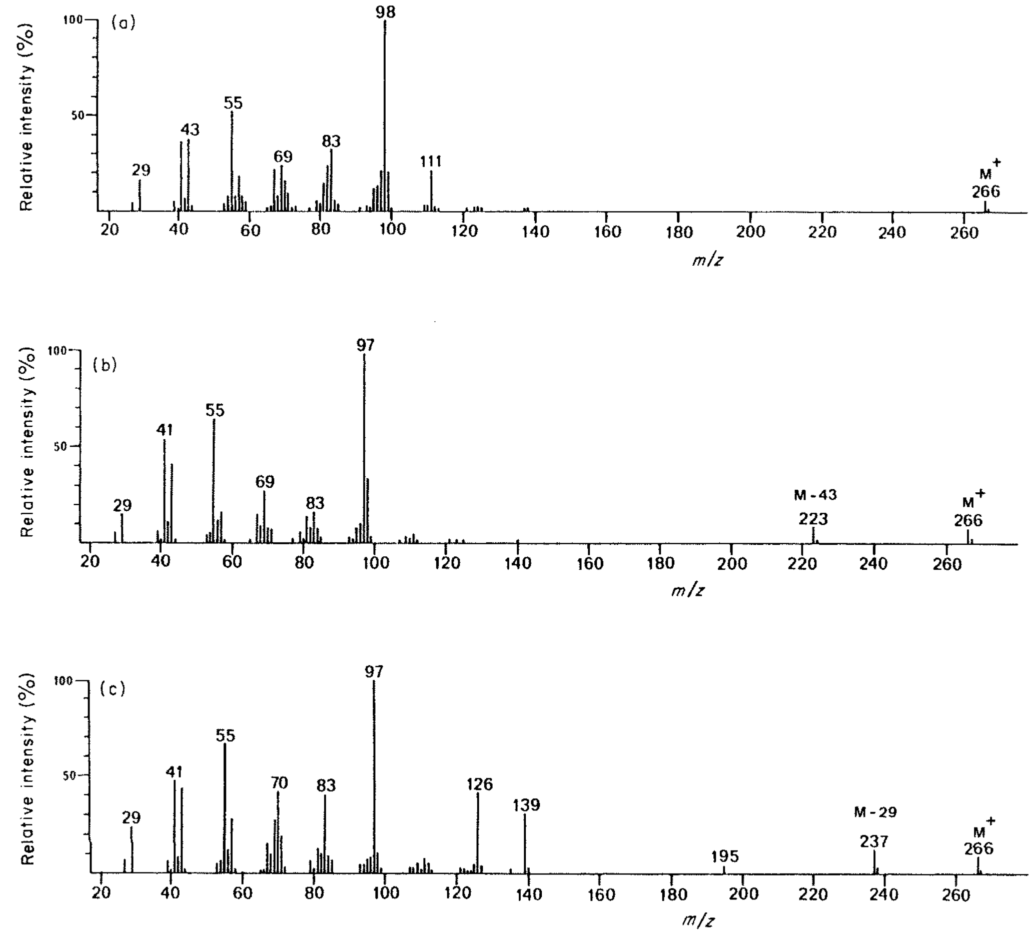

Figure 5. Electron impact mass spectra of (a) 2-*n*-dodecylcyclohexanone, (b) 3-*n*-dodecylcyclohexanone, and (c) 4-*n*-dodecylcyclohexanone.

These fragmentation rules have been applied successfully to the three isomeric *n*-dodecylcyclohexanones (Fig. 5). The presence of a peak at *m*/*z* 195 on the mass spectrum of the 4-*n*-dodecylcyclohexanone (Fig. 5(c)) which corresponds with the fragment ion *s* (*m*/*z* 83) of the 4-*n*-butylcyclohexanone (Fig. 3), constitutes a supplementary proof of the validity of the proposed fragmentation mechanisms.

Consequently, gas chromatography/electron impact mass spectrometry is a useful technique permitting the differentiation of the positional isomers of *n*-alkylcyclohexanones with a long side chain.

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