The Reaction of Tris(4-methoxyphenyl)methyl Chloride with Sodium Methoxide—Non-operation of Single Electron Transfer Pathways

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Tris(4-methoxyphenyl)methyl chloride (2) and sodium methoxide furnish, in methanol as well as in aprotic solvents, the normal substitution product methyl tris(4-methoxyphenyl)methyl ether (3) with partial replacement of the p-methoxy-groups of the substrate by the reagent. No reduction to tris(4-methoxyphenyl)methane takes place unlike the reaction in the absence of sodium methoxide (during which reaction exchange of methoxy-groups between substrate and methanol occurs to a much greater extent) and no single electron transfer products are formed unlike the reaction of triphenylmethyl halides (1a, b) and sodium methoxide. These differences are rationalized by invoking the irreversibility of formation of compound (3) by attack of methoxide at the central carbon atom of cation (12) as contrasted to the reversibility of formation of the conjugate acid of (3), (14), resulting from attack of methanol at the same site, and also the different stabilities and tendencies of formation of the tris(4-methoxyphenyl)carbenium (12) and triphenylcarbenium ions, respectively.

Recently we have shown that, in contrast to triphenylmethyl chloride (1a), which under similar conditions is simply solvolyzed to yield methyl triphenylmethyl ether, tris(4-methoxyphenyl)methyl chloride (2), when refluxed with methanol for prolonged periods, is reduced to tris(4-methoxyphenyl)methane, and that in the course of this reduction exchange of methoxy-groups between substrate and solvent takes place to a considerable extent. The different behaviour of the two triarylmethyl chlorides (1a) and (2) was rationalized in terms of the greater stability and greater tendency of formation of the tris(4-methoxyphenyl)carbenium ion (12).[1]
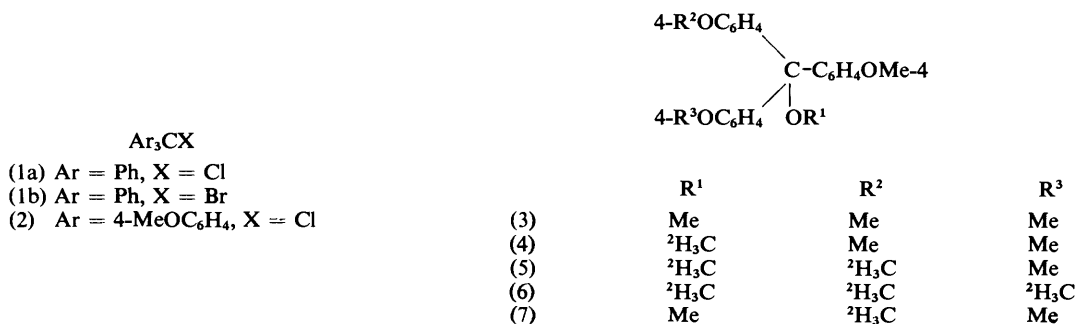
In continuation of this investigation we have now studied the reaction of the triarylmethyl compound (2) with an excess of sodium methoxide in various refluxing solvents including methanol, tetrahydrofuran (THF), dioxan, 2,2-dimethoxypropane (DMP), and 1,2-dimethoxyethane (DME). In all five solvents the normal substitution product, methyl tris(4-methoxyphenyl)methyl ether (3) was obtained in ca. 85% yield. Thus, the reactivities of the triarylmethyl compounds (1a) and (2) differ considerably also in the presence of sodium methoxide, especially in non-protic solvents, since the chloro-compound (1a) [as well as the corresponding bromide (1b)] are known to furnish, on treatment with sodium methoxide in DMP both under nitrogen and in air, substantial amounts of the reduction product triphenylmethane (17—21%) and, in air, small amounts of ditrityl peroxide, in addition to methyl

trityl ether (28—33%) and p-methoxytriphenylmethane (8) (5—10%), the normal and *tele*-substitution products, respectively.[2] Similar results were obtained also with potassium t-butoxide in DMP under nitrogen, the main difference being that, with the latter reagent, about 20% of the dimeric compound (9) was also isolated.[3] Moreover, according to preliminary experiments carried out in the course of the present study, the reduction product triphenylmethane is also obtained from the bromo-compound (1b) when it is allowed to react with sodium methoxide in diethyl ether, dioxan, or THF.

Some experimental observations have suggested [2,3] that the formation of triphenylmethane, the p-xylene (9), and ditrityl peroxide involves the intermediacy of triphenylmethyl radicals, obviously formed via the radical anions (10); the latter are the products of single electron transfer (SET) to the halides (1) [equation (1)] while methyl trityl ether and the methoxy-compound (8) are formed via ionic (*i.e.* non-SET or, more specifically, non-$S_{RN}1$) processes.

$$Ph_3CX \xrightarrow{SET} [Ph_3CX]^{\cdot-} \longrightarrow Ph_3C^{\cdot} + X^- \quad (1)$$
$$(1a, b) \qquad (10)$$
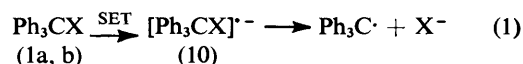
Thus, SET pathways appear to compete effectively with nucleophilic substitutions in the case of the halides (1). The non-formation of the corresponding triarylmethane and bis-(triarylmethyl) peroxide from the chloride (2) therefore must
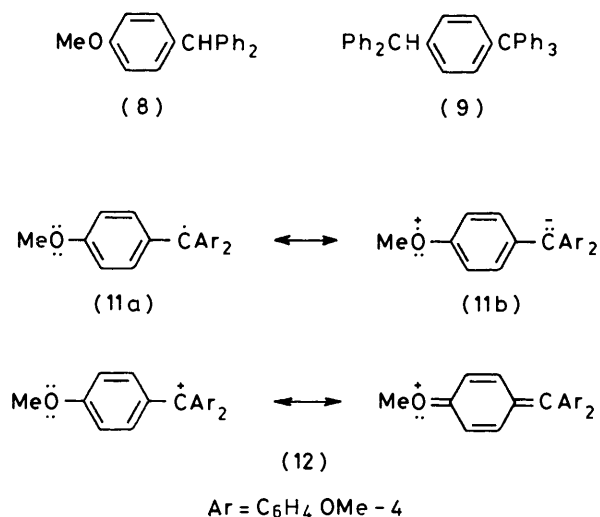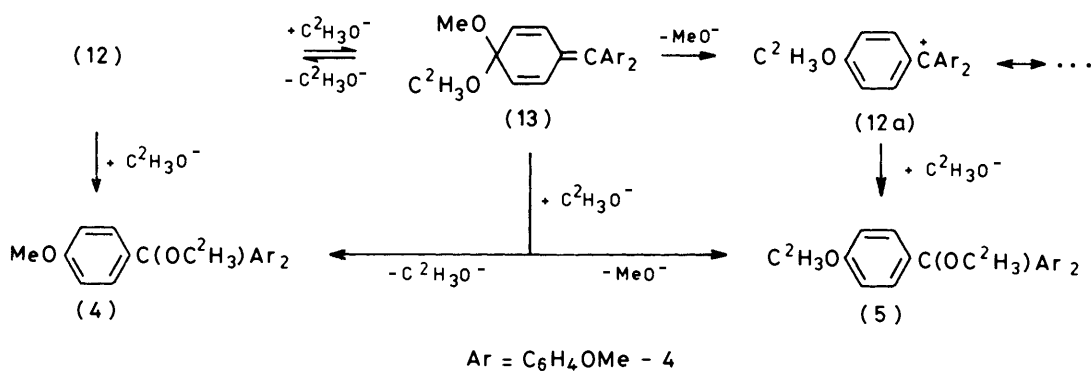
$$4\text{-}R^2OC_6H_4$$
$$\diagdown$$
$$C\text{-}C_6H_4OMe\text{-}4$$
$$\diagup \;|$$
$$4\text{-}R^3OC_6H_4 \quad OR^1$$

Ar₃CX

(1a) Ar = Ph, X = Cl
(1b) Ar = Ph, X = Br
(2) Ar = 4-MeOC₆H₄, X = Cl

	R¹	R²	R³
(3)	Me	Me	Me
(4)	²H₃C	Me	Me
(5)	²H₃C	²H₃C	Me
(6)	²H₃C	²H₃C	²H₃C
(7)	Me	²H₃C	Me

MeO⟨⟩CHPh₂

(8)

Ph₂CH⟨⟩CPh₃

(9)

MeÖ—⟨⟩—ĊAr₂ ⟷ MeÖ⁺—⟨⟩—C̄Ar₂

(11a)

(11b)

MeÖ—⟨⟩—ĊAr₂ ⟷ MeÖ⁺=⟨⟩=CAr₂

(12)

Ar = C₆H₄OMe - 4

Table 1. Compositions [a] of the mixtures of the trimethoxy-compound (3) and its deuteriated analogues resulting from the reaction of the triarylmethyl compound (2) with sodium [²H₃]-methoxide [b,c] in [²H₄]methanol and tetrahydrofuran

Compound	Solvent		
	[²H₄]Methanol [b]	THF Run 1	Run 2
(3)		3.3 [d]	1.8
(4) [e]	99.0 ± 0.5 [f]	92.5	95.8
(5)	1.0 ± 0.5	4.1	2.4
(6)	<0.03	0.1 [g]	0.2

[a] Determined by mass spectrometry, see Experimental section. [b] 99.5 Atom % ²H. [c] 4 Mol equiv. [d] Detected also by ¹H n.m.r. spectroscopy. [e] This compound may, in principle, be contaminated by small amounts of its isomer (7) [cf. the formation of compound (3)], which, however, could be detected neither by mass nor by ¹H n.m.r. spectrometry. [f] % Compositions. [g] Amount of the analogue containing four [²H₃]methoxy-groups <0.01%.

(12) ⇌(+C²H₃O⁻ / −C²H₃O⁻) MeO⟨⟩=CAr₂ / C²H₃O —MeO⁻→ C²H₃O⟨⟩ĊAr₂ ⟷ ...

(13) (12a)

↓ +C²H₃O⁻   ↓ +C²H₃O⁻   ↓ +C²H₃O⁻

MeO⟨⟩C(OC²H₃)Ar₂ ←(−C²H₃O⁻ / −MeO⁻)→ C²H₃O⟨⟩C(OC²H₃)Ar₂

(4)   (5)

Ar = C₆H₄OMe - 4

Scheme 1.

mean that here no tris(4-methoxyphenyl)methyl radicals (11) are formed; that is, that no SET pathways operate and compete with nucleophilic substitution in this case. In view of the fact that compound (2) exists in methanol in the dissociated ionic form while in the non-dissociating solvents THF, DMP, DME, and dioxan it may be assumed to exist in the form of ion-pairs,* formation of the radicals (11) via the radical-anions of the non-ionized compound (2) appears to be hardly possible. Moreover, SET to the cations (12) to form the radicals (11) should also be extremely difficult since, in contrast to the cations (12), there is no extra resonance stabilization (resulting from the presence of the *p*-methoxy-groups) in the radicals (11). [Note the unfavourable charge distribution of resonance form (11b).]

Thus, it is suggested that the differences in the reactivities of compounds (1) and (2) towards methoxide ions are related to the different stabilities and tendencies of formation of the corresponding triarylcarbenium ions which, under the conditions of the present study, undergo exclusively ionic substitution.

Subsequently we have investigated the possibility that the reaction (2) ⟶ (3) is also accompanied by replacement of

one or more methoxy-groups of the substrate by the reagent methoxide [similarly to the exchange of methoxy-groups between substrate and solvent methanol accompanying the reduction of the triarymethyl compound (2) by methanol to the corresponding triarylmethane [1]]. Compound (2) was therefore allowed to react with sodium [²H₃]methoxide (99.5 atom % ²H) (4 mol equiv.) in [²H₄]methanol (99.5 atom % ²H) and THF to give mixtures of deuteriated analogues of compound (3) in 84 and 90% yield, respectively, the main component of the mixtures being, as shown by mass and ¹H n.m.r. spectrometry, compound (4). The compositions of the mixtures as determined by mass spectrometry (see Experimental section) are shown in Table 1.

The formation of compounds (5) and (6) demonstrates that, although attack of [²H₃]methoxide ions takes place overwhelmingly at the central carbon atom, the ion-pair (12) · · · Cl⁻ (in THF) as well as, to a somewhat lesser extent, the cation (12) (in [²H₄]methanol) may be attacked also at one of the *para*-positions to furnish the methylene intermediate (13). The latter may either lose [²H₃]methoxide and revert to (12) or, by loss of methoxide, furnish the labelled cation (12a) which upon attack of a second [²H₃]methoxide anion will then furnish the deuteriated methoxy-compound (5) (Scheme 1). Starting with cation (12a) rather than with cation (12), the formation of compound (6) may similarly be rationalized.

An alternative mode of formation of compound (5) should also be considered, namely attack of a second [²H₃]methoxide ion at the central carbon atom of the methylene intermediate

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* This assumption is based on the results of electrical conductivity measurements [4] as well as on an X-ray study [5] which has shown that the C–Cl distance in the crystals of the triarylmethyl compound (2) is somewhat larger than the sum of the covalent radii of the two atoms.
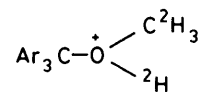
(13) with simultaneous expulsion in anionic form of the methoxy-group from the non-aromatic ring (*tele*-substitution by the S_N2' mechanism).* If the [$^2H_3$]methoxy- rather than the methoxy-group is expelled in the course of this reaction, formation of the less deuteriated compound (4) rather than of (5) will be the result. Since the latter mode of formation of compounds (4) and (5) does not require ionic dissociation of the intermediate (13) (which should be a comparatively unfavoured process) it is probably the preferred pathway of formation of these compounds.

Support for the view that ionic dissociation of the neutral adduct (13) must be a comparatively unfavoured process comes from the fact that the non-labelled compound (3) was observed among the products of the reaction of compound (2) with sodium [$^2H_3$]methoxide in THF (Table 1). A rough calculation shows that, in the course of this reaction, on average *ca.* 1 mol of the introduced 4 mol of sodium [$^2H_3$]methoxide is consumed in the formation of compounds (4)—(6) with simultaneous liberation of, on average, 0.036 mol of sodium methoxide. That is, if, by the ionic dissociation of adduct (13), the methoxide ions really became free in the course of the reaction, the ratio of methoxide and unused [$^2H_3$]methoxide ions *at the end* of the reaction would be $0.036/(4-1)$, *i.e.* 1.2%. Thus, the *average value* of 0.60% may be assumed for this ratio in the course of the reaction. Therefore, the formation of, on average, 2.5% of the non-labelled compound (3) in this reaction would be difficult to explain on the basis of the competition [for the cation (12)] of methoxide and [$^2H_3$]methoxide ions alone. The chance of formation of compound (3) would be enhanced if another (minor) pathway, possibly that shown in [equation (2)], were to contribute to the formation of compound (3), because here the chances of abstraction by the cation (12) of a methoxy- and a [$^2H_3$]-methoxy-group from the intermediate (13) should be practically equal.†
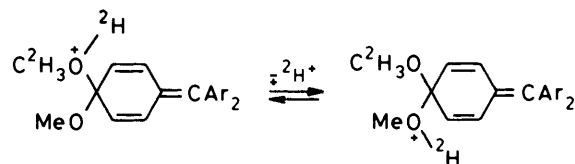

(12)   (13)

(Ar = 4 -MeOC$_6$H$_4$)
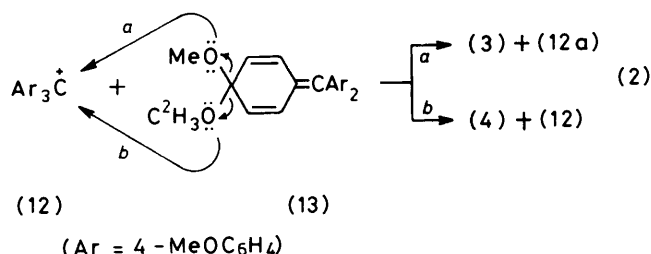
The extent of replacement of the *p*-methoxy-groups of the substrate by [$^2H_3$]methoxide during the reaction (2) ⟶ (3) is considerably lower than that of the replacement of the *p*-methoxy-groups of the substrate by the solvent/reagent, [$^2H_4$]methanol, during the reduction of compound (2) to tris(4-methoxyphenyl)methane.[1] A possible explanation for this phenomenon is as follows.

Clearly, both the cation (12) and the ion-pair (12) ··· Cl⁻ are predominantly attacked both by [$^2H_3$]methoxide anions and [$^2H_4$]methanol molecules at the central carbon atom to furnish compound (4) and its conjugate acid (14), respectively. However, while formation of compound (4) is irreversible,
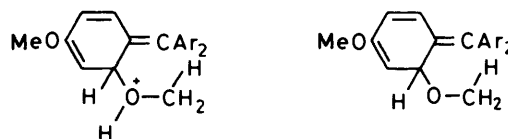
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* For possibly related *tele*-substitutions see ref. 3.
† In agreement with this view is [since cation (12a) is one of the precursors of compound (5) (Scheme 1)] the observation that the changes in the amounts of products (3) and (5) formed in the two runs of the reaction of compound (2) and sodium [$^2H_3$]methoxide in THF are similar (Table 1).

(14)

Ar = C$_6$H$_4$OMe - 4

(15a)   (15b)

Ar = C$_6$H$_4$OMe - 4

Scheme 2.

(16)   (17)

Ar = C$_6$H$_4$OMe - 4

formation of the cation (14) is reversible. Cation (12) is therefore continuously regenerated in the reaction with [$^2H_4$]-methanol until it is ultimately attacked by [$^2H_4$]methanol at one of the *para*-positions to yield the cation (15a). The latter furnishes the tautomer (15b) by prototropy, and, by subsequent loss of [O-^2H]methanol, the cation (12a), the overall result being replacement of a *p*-methoxy- by a [$^2H_3$]methoxy-group (Scheme 2).

The observation that compound (2) is reduced to tri(4-methoxyphenyl)methane by methanol but not by methoxide may be explained on a similar basis. The crucial step in the reduction is formation of the *ortho*-adduct (16)[1] which may take place because of the reversibility of the formation of the cation (14). The corresponding *ortho*-adduct (17), on the other hand, is not formed with methoxide (or only to a negligible extent) because of the overwhelming and irreversible formation of compound (4).

Experimental

The abundance ratios of the components (3)—(6) in the products obtained by allowing compound (2) to react with [$^2H_3$]methoxide in [$^2H_4$]methanol and THF, respectively, were determined by measuring the relative intensities of the peaks of the molecular ion bundle in the mass spectra obtained at 9 eV nominal ionizing electron energy (at which no fragmentation takes place) and, in one case, by measuring in addition the relative abundances of the $(M - 4\text{-}CH_3OC_6H_4)$ and $(M - 4\text{-}C^2H_3\text{-}OC_6H_4)$ fragment ions in the 70 eV mass spectrum, taking into

Table 2. Reaction of tris(4-methoxyphenyl)methyl chloride (2) with sodium methoxide

Starting reagents/ mmol			Reaction	Yield of (3)[a]/
(2)	NaOMe	Solvent (amount/ml)	time/h	%
1.35	5.4	MeOH (10)	5	85
2.7	10.8	MeOH (20)	5	87
2.0	8.0	THF [b] (10)	5	89
2.0	8.0	Dioxan [b] (10)	5	85
5.5	22	DMP [b] (20)	8	84
2.0	8.0	DME [b] (10)	5	80

[a] The identity of the various samples of compound (3) was checked by comparing their i.r. spectra. [b] Refluxed for 6 h with, and freshly distilled from, LiAlH₄.

Table 3. Reaction of tris(4-methoxyphenyl)methyl chloride (2) with sodium [²H₃]methoxide [a]

Experiment no.	Starting reagent/mmol		Solvent (amount/ ml)	Reaction time/h	Yield [b]/ %
	(2)	Na-OC²H₃			
1	2.2	8.8	C²H₃O²H [a] (5)	5	84
2	2.0	8.0	THF [c] (10)	5	92
3	2.0	8.0	THF [c] (10)	5	90

[a] 99.5 Atom % ²H. [b] For the compositions of the resulting mixtures of compound (3) and its deuteriated analogues, see Table 1. [c] Refluxed for 6 h with, and freshly distilled from, LiAlH₄.

account the natural isotopic abundances.The reproducibilities of the measurements were *ca.* 0.5% and their accuracies *ca.* 2%.

[²H₄]Methanol (99.5 atom % ²H) was purchased frcm EGA-Chemie, Steinheim, W. Germany. Sodium [²H₃]methoxide was obtained from this reagent on treatment with metallic sodium; the ²H content of the product was checked by ¹H n.m.r. and mass spectrometry after it had been converted into [²H₃]methyl diphenylacetate as described in ref. 1.

Reaction of Tris(4-methoxyphenyl)methyl Chloride (2) *with Sodium Methoxide.*—Mixtures of compound (2) with sodium methoxide (4 mol equiv.) in various solvents were refluxed with continuous stirring for 5—8 h under nitrogen. Except for the reaction conducted in methanol, the reaction mixtures remained throughout heterogeneous. The solvents were distilled off under reduced pressure and the residues were triturated with anhydrous diethyl ether (30 ml). The insoluble material was filtered off and the filtrates were evaporated to dryness to give light yellow oils; these were crystallized from hexane to give compound (3), m.p. 76—78 °C. For details and yields, see Table 2 [Found: C, 76.1; H, 6.75. C₂₃H₂₄O₄ (364.45) requires C, 75.80; H, 6.64%]; δ (CDCl₃) 3.0 (s, 3 H), 3.7 (s, 9 H), and 6.76 and 7.27 (AA'BB', *J* 8.8 Hz, 12 H); δ (¹³C) (CDCl₃) 51.8 (aliphatic MeO), 55.1 (aromatic MeO), 86.1 (Ar₃C–O), 113.0, 129.8, 136.7, and 158.3 p.p.m. (aromatic C-3 and -5, C-2 and -6, C-1 and -4, respectively).

Reaction of Tris(4-methoxyphenyl)methyl Chloride (2) *with Sodium* [²H₃]*Methoxide.*—These reactions were carried out and the resulting mixtures were worked up as described above, but with sodium [²H₃]methoxide instead of sodium methoxide (see Table 3).

Details of the ¹H n.m.r. spectra of the products are as follows.

Experiment no. 1: δ 3.75 (s, aromatic MeO), 6.75 and 7.26 (AA'BB', ArH); intensity ratio 2.93 : 4; *no* aliphatic MeO

Table 4. Relative intensities of the peaks of the molecular ion bundle in the 9 eV mass spectrum, and of the (*M* − 4-CH₃OC₆H₄) and (*M* − 4-C²H₃OC₆H₄) ion bundle in the 70 eV mass spectrum of the product of the reaction of the triarylmethyl compound (2) and sodium [²H₃]methoxide in [²H₄]methanol

	Relative intensity/%	
m/z	Found	Calc.[a]
(a) Molecular ion bundle		
371	0.2	0.0
370	1.2	0.2
369	4	3
368	24	26
367	100	100
366	3	0.0
365	0.0	0.0
(b) (*M* − CH₃OC₆H₄) and (*M* − C²H₃OC₆H₄) ion bundle		
264	0.4	0.0
263	1.0	0.1
262	3	2
261	16	17
260	100	100
259	5	0.0
258	1.5	0.0

[a] For the presence of three ²H atoms, taking into account the natural isotopic abundances.

Table 5. Relative intensities of the peaks of the molecular ion bundles in the 9 eV mass spectra of the products of the reactions of the triarylmethyl compound (2) and sodium [²H₃]methoxide in tetrahydrofuran

m/z	Relative intensities [a]/%		Number of ²H atoms
	Experiment 2 [b]	Experiment 3 [b]	
375	0.01		
374	0.02		
373	0.1	0.2	9
372	0.2	0.2	
371	1.1	0.7	
370	4.6	2.7	6
369	4.1	4.3	
368	25	25	
367	100	100	3
366	2.1	2.7	
365	1.0	0.8	
364	3.6	1.9	0

[a] Observed values, not corrected for natural isotopic abundances. [b] See Table 3.

signal. Experiment no. 2: aromatic MeO and ArH signals as above, intensity ratio 2.99 : 4; aliphatic MeO signal just recognizable. Experiment no. 3: aromatic MeO and ArH signals as above, intensity ratio 2.83 : 4; aliphatic MeO signal just recognizable.

The product from Experiment no. 1 gave the following mass spectrum (70 eV; 160 °C): *m/z* (relative intensity, number of ²H atoms, type of ion) 367 (21, 3, *M*); 333 (100, 0, *M* − OC²H₃), 260 (31, 3, *M* − MeOC₆H₄), and 135 (28, 0). For the relative intensities of the peaks of the molecular, and the (*M* − 4-CH₃OC₆H₄) and (*M* − 4-C²H₃OC₆H₄) ion bundles, see Tables 4 (Experiment 1) and 5 (Experiments 2 and 3). For the relative abundances of the different components of the mixtures calculated from the relative intensities shown in Tables 4 and 5, see Table 1.

References

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