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Kinetic study of methoxide-promoted elimination reactions of some 1,1,1-trichloro-2,2-bis(phenyl-substituted)ethanes

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ABSTRACT: The methoxide-promoted elimination reaction of some 1,1,1-trichloro-2,2-bis(phenyl-substituted)ethanes (**1**) was investigated. The *ortho*-substituted derivatives were found to be less reactive than the corresponding *ortho*-unsubstituted derivatives, irrespective of the nature of their substituent. The reactivity data were correlated with the ^{13}C NMR chemical shift values of C-β of either 1,1,1-trichloro-2,2-bis(phenyl-substituted)ethanes or 1,1-dichloro-2,2-bis(phenyl-substituted)ethenes and the better result was obtained for the former correlation. Activation parameters for the methoxide-promoted elimination of **1** show very similar values for *ortho*-substituted derivatives. The total data set seems to be more indicative, even if not compelling, of an irreversible *E*1*cB* mechanism. Copyright © 2001 John Wiley & Sons, Ltd.

KEYWORDS: 1,1,1-trichloro-2,2-bis(phenyl-substituted)ethanes; reaction mechanism; base-promoted elimination; ^{13}C NMR

INTRODUCTION

The β-elimination reaction[1] is one of the most studied reactions in organic chemistry. It is well known[2] that both the electronic and steric properties of a β-substituent (generally an aryl-substituted ring) are able to affect the reactivity of base-promoted elimination. Furthermore, in some cases, the β-substituent seems to be responsible for changing the elimination mechanism from concerted *E*2 to stepwise *E*1*cB*.[2]

We recently studied the base-promoted elimination reaction of some 1,1,1-trihalo-2,2-bis(dimethoxyphenyl)-ethanes in alcoholic solutions.[3] The reported data did not allow definite conclusions as regards the nature of the reaction mechanism (i.e. irreversible *E*1*cB* or *E*2), thereby confirming similarity between the two mechanisms.[1,4] Our interest in the properties of 1,1-diarylethanes and, in particular, the effect of *ortho*-substituents on the reactivity of 1,1-diarylethanes[5] prompted us to carry out a kinetic study of the methoxide-promoted elimination reaction of some 1,1,1-trichloro-2,2-bis(phenyl-substituted)ethanes (**1a–j**) with at least one *ortho*-substituted aromatic ring. For comparison, we also report data for the bis(3,4-dimethoxyphenyl) (**1k**) and bis(4-methoxyphenyl) (**1l**) derivatives. *Ortho*-substitution on either **1k** or **1l** should change the steric requirements of aromatic rings, consequently deeply affecting the elimination reaction.

The kinetic studies of dehydrochlorination of **1a–e, g** and **l**, which produce the corresponding 1,1-dichloro-2,2-bis(phenyl-substituted)ethenes (**2a–e, g** and **l**), were performed over the temperature range 30–50 °C at various concentrations (from 0.04 up to 0.4 M, depending on the studied substrate) of sodium methoxide. Compounds **1h–j** showed very low reactivity under these reaction conditions, so, in order to obtain some information about their reactivity, Hammett's equation was used to calculate second-order constant values, with compound **1f**[3] as a reference and assuming additive substituent effects.

RESULTS AND DISCUSSION

The second-order rate constants for the methoxide-promoted elimination of **1a–l**, together with the ^{13}C NMR chemical shift values of the C-β carbon atom for **1a–l** and **2a–l**, are reported in Table 1. We observed that the introduction of an *ortho*-substituent on at least one aromatic ring causes a significant decrease in the second-order rate constant, irrespective of the electron-withdrawing/releasing nature of the substituent. Indeed, the substitution of one *ortho*-hydrogen atom of **1k** by one nitro group (**1a**) decreases the rate constant by a factor of 2, $k_{\mathbf{1k}}/k_{\mathbf{1a}} = 2$, although the electron-withdrawing effect of the nitro group should act in the opposite direction. For

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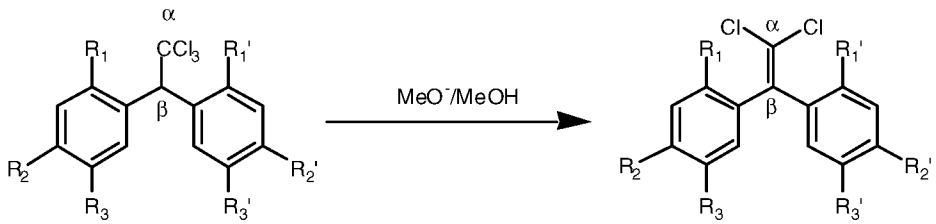

1 2

	R_1	R_2	R_3	R_1'	R_2'	R_3'
a	NO_2	OMe	OMe	H	OMe	OMe
b	I	OMe	OMe	H	OMe	OMe
c	Br	OMe	OMe	H	OMe	OMe
d	Me	OMe	OMe	H	OMe	OMe
e	Me	OMe	OMe	Me	OMe	OMe
f	OMe	H	OMe	OMe	H	OMe
g	OMe	H	H	H	OMe	H
h	OMe	H	Me	OMe	H	Me
i	OMe	OMe	OMe	OMe	OMe	OMe
j	OMe	OMe	H	OMe	OMe	H
k	H	OMe	OMe	H	OMe	OMe
l	H	OMe	H	H	OMe	H

example, the hydroxide ion-promoted reaction of 2-(4-nitrophenyl)ethyl bromide is about 100 times faster than that of phenylethyl bromide.[2b]

A comparison of homologous mono-*ortho*-substituted compounds (**1a–d**) shows clearly that both the steric and electronic effects must be responsible for the observed reactivity order. Indeed, **1b** with the bulkiest substituent, i.e. I, is less reactive than **1d** (with an electron-releasing *ortho*-substituent, i.e. Me), **1a** and **1c** (with electron-withdrawing *ortho*-substituents). It is interesting that the same decrease in reactivity is observed on going from **1k** to **1d** (i.e. from an *ortho*-unsubstituted to an *ortho*-methyl-substituted derivative, $k_{\mathbf{1d}}/k_{\mathbf{1k}} = 0.11$) and from **1d** to **1e** (i.e., from an *ortho*-methyl to a bis-*ortho*-methyl-substituted derivative, $k_{\mathbf{1e}}/k_{\mathbf{1d}} = 0.15$). The observed decrease in reactivity from **1k** to **1e** could be a consequence of both the steric and electronic effects of the *ortho*-methyl groups in **1e**.

The replacement of *ortho*-methyl groups in **1e** by *ortho*-methoxy groups (**1i**) causes a substantial decrease in reactivity ($k_{\mathbf{1i}}/k_{\mathbf{1e}} = 6 \times 10^{-3}$), in contrast to the result predicted only on the grounds of differences in steric requirements of these substituents ($\Delta E_s = 0.69$).[6] Hence there must be a significant and unfavourable electronic effect that can only be explained by considering that an elimination mechanism with a carbanionic transition state is operating. Thus, the observed reactivity order can be derived from the usual electronic effect of the substituents and other *ortho*-effects, as in the case of steric hindrance to conjugation.

Indeed, if we consider that two mechanisms (i.e. irreversible *E*1*cB* and *E*2) can operate in the dehydrochlorination of **1**, the steric hindrance to conjugation of aromatic rings with a carbanionic centre (irreversible *E*1*cB* mechanism) should cause a decrease in reactivity, as a consequence of a decrease in acidity of the *β*-

Table 1. ^{13}C NMR C-*β* chemical shift values (ppm) for **1a–l** and **2a–l** and second-order rate constants ($dm^3\ mol^{-1}\ s^{-1}$)[a] for the **1** → **2** reaction in MeO^-–MeOH at 40 °C

Compound	C-*β* of **1**	C-*β* of **2**	*k*	Log*k*
a	61.29	136.72	5.43×10^{-4}	−3.26
b	71.98	141.10	2.61×10^{-5}	−4.58
c	67.16	138.61	9.30×10^{-5}	−4.03
d	64.87	139.26	1.12×10^{-4}	−3.95
e	59.84	139.01	1.71×10^{-5}	−4.77
f	52.12	134.01	1.77×10^{-6}[b]	−5.75
g	60.28	137.02	1.21×10^{-5}	−4.92
h	51.90	134.17	$\sim 10^{-7}$; 3.86×10^{-7}[c]	−6.41
i	51.54	134.06	$\sim 10^{-7}$; 6.83×10^{-7}[c]	−6.17
j	51.33	134.03	$\sim 10^{-7}$[b]; 3.24×10^{-7}[c]	−6.49
k	70.10	139.81	1.04×10^{-3}[b]	−2.98
l	69.55	139.66	4.00×10^{-4}	−3.40

[a] The rate constants are accurate to within ±3%.
[b] From Ref. 3.
[c] Calculated values.

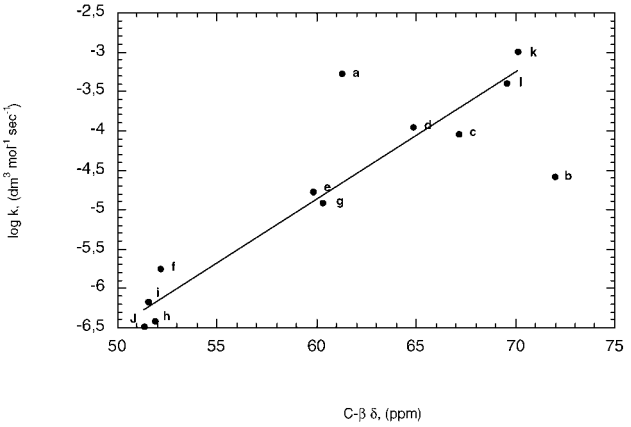

Figure 1. Plot of the logarithms of the rate coefficients for the **1** → **2** reaction in MeO^-–MeOH at 40 °C versus ^{13}C NMR C-β chemical shifts of compounds **1**. The values are reported in Table 1

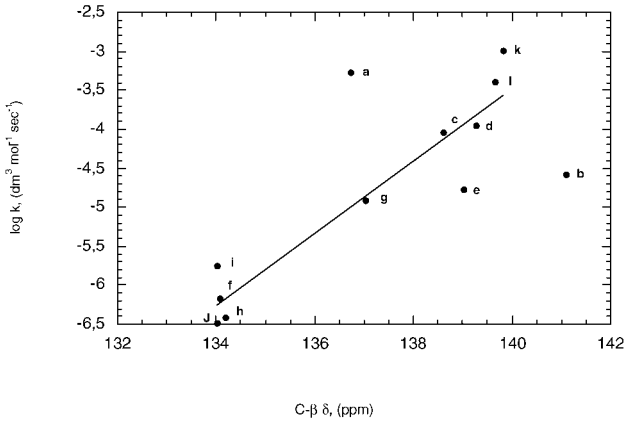

Figure 2. Plot of the logarithms of the rate coefficients for the **1** → **2** reaction in MeO^-–MeOH at 40 °C versus ^{13}C NMR C-β chemical shifts of compounds **2**. The values are reported in Table 1

hydrogen atom. Furthermore, an *ortho*-substituent should also be able to hinder the conjugation between the aromatic ring and π-electrons of the double bond, thereby causing an increase in the energy of the elimination product and consequently an increase in the transition-state energy (*E*2 mechanism).

Considering that the reactivity of compounds **1a–j**, though affected by *ortho* effects, seems to depend on electronic factors, we attempted to correlate the reactivity data with C-β ^{13}C NMR chemical shift values. ^{13}C chemical shift values can be considered a measure of the electron density of carbon atoms[7] when the electron excitation energy term in the Karplus–Pople[8] equation is constant for the series under examination.

According to the chemical shift values reported in Table 1, it can be observed that the presence of one *ortho*-substituent, excluding the iodo derivative, determines a significant upfield shift for the C-β carbon atom. A downfield shift of carbon atoms, as induced by an iodo atom in the γ-position (the effect of the *ortho*-iodo substituent on C-β in our case), was observed and accounted for by 1-iodonaphthalene.[9]

Figure 1 shows the result of the correlation between the logarithm of second-order kinetic constants for methoxide-promoted elimination and the C-β ^{13}C NMR chemical shift values of **1**. As can be seen, a good correlation ($s = 0.16 \pm 0.01$, $i = -14.6 \pm 0.6$, $n = 10$, $r = 0.983$) was obtained and only two points, which relate to mononitro and -iodo derivatives, deviate significantly. Presumably these deviations are the result of the peculiar effects exerted by *ortho*-iodo (see above) and the *ortho*-nitro substituents on the C-β ^{13}C NMR chemical shift, that does not influence the reactivity of **1a** and **1b** in the elimination reaction. For the *ortho*-nitro group, it is possible to suppose that different preferable conformations, i.e. coplanar and perpendicular, are responsible for spectroscopic and reactivity behaviour.

According to the hypothesis that the methoxide-promoted dehydrochlorination reaction of **1** occurs via an *E*2 mechanism, reactivity data were also correlated with the C-β ^{13}C NMR chemical shift values of **2** (Fig. 2). Points relating in this case to **2a** and **b** deviate significantly and, moreover, this correlation ($s = 0.47 \pm 0.05$, $i = -69 \pm 8$, $n = 10$, $r = 0.948$) is worse than the previous one.

In our opinion, the linear correlation obtained for **1** could be considered as an indication that the compounds under investigation in this study react as the same reaction mechanism. The positive value of the slope probably indicates that the reaction mechanism is carbanionic in nature (*E*1*cb* or *E*2): the greater the electron density on the C-β carbon atom in the ground state (upfield chemical shift), the more difficult is the formation of a negative charge on C-β.

The activation parameters of methoxide-promoted elimination for **1a–e** and **k** are reported in Table 2. Both the enthalpy and entropy values for *ortho*-substituted compounds **1a–e** are not much higher than those for **1k**. However, the *ortho*-substituted compounds have very similar activation parameters [the activation enthalpy values do not differ by more than 1 kcal mol^{-1} (1 kcal = 4.184 kJ) and the activation entropy values differ by more than 3 entropy units (e.u.) on going from the more reactive **1a** to the less reactive **1e**]. This seems to indicate that the differences in reactivity among these compounds are essentially electronic in nature. We could expect large but random variations in entropic factors when the steric effects are operative. For example, in the methoxide-promoted dehydrochlorination of 1-chloro-1,1-difluoro-2-phenylethanes,[10] the presence of bulky *ortho*-substituents causes a decrease in the activation entropy values that ranges from −0.5 to −9.2 e.u.

Finally, the enthalpy values similar to those that we calculated have been reported for the methoxide-promoted irreversible *E*1*cB* elimination of some 1,1,1-trichloro-2,2-diphenyl-substituted ethanes.[2a] Conversely,

Table 2. Activation parameters[a] for the **1** → **2** reaction in MeO^-–MeOH

Compound	$\Delta H‡$[b] (kcal mol^{-1})	$-\Delta S‡$[a,c] (cal K^{-1} mol^{-1})
1a	19.7	11
1b	20.5	14
1c	19.8	14
1d	20.4	11
1e	22.2	10
1k	17.2[d]	17[d]

[a] Calculated from kinetic data collected in the temperature range 30–50 °C.
[b] Calculated at 40 °C; experimental error ~700 cal mol^{-1}.
[c] Calculated at 40 °C; experimental error ~2 cal K^{-1} mol^{-1}.
[d] From Ref. 3.

enthalpy and entropy values for ethoxide-promoted *E*2 eliminations of 1-bromo-2-phenylethane and -propane[11] are lower and higher, respectively, than those reported here. Hence we can suppose that the substrates studied in this work probably react in their dehydrochlorination reaction via an irreversible *E*1*cB* mechanism.

This conclusion could also be supported by the fact that the C-β ^{13}C NMR chemical shift values of **1** describe reactivity data better than those of **2**, as shown by the results of relative correlations. This fact is interesting because it is usually difficult to predict the reactivity of polysubstituted aromatic compounds. It seems possible to estimate the reactivity of compounds such as **1** versus the dehydrochlorination reaction by means of a unique parameter which is linked to the overall effect of the substituents, that is, the C-β ^{13}C NMR chemical shift values.

EXPERIMENTAL

Melting-points were measured on a Büchi 510 melting-point apparatus and are uncorrected. High-resolution mass spectrometry (HRMS) spectra were performed on an AutoSpec O-TOF instrument (Micromass) at a resolving power of 10 000 with an accuracy of ±10 ppm. IR spectra were obtained with a Perkin-Elmer Model 1310 IR spectrophotometer. ^{1}H and ^{13}C NMR spectra were recorded on a Bruker AC-E 250 MHz spectrometer in deuterochloform solutions. Chemical shifts are reported as δ values (ppm) relative to residual $CHCl_3$ (7.27 ppm) for ^{1}H NMR. ^{13}C NMR chemical shift values are reported as δ values (ppm) with respect to solvent central peak signals (77.00 ppm) and were taken from fully decoupled spectra. C-β carbon signals assignment was made on the ground of known substituent effects and, when necessary, mult-ellipticities were also determined by 'proton gated' decoupled experiments. For **1a–d** and **2a–d** H′ and C′ refer to protons and carbons of the 3,4-dimethoxy-substituted phenyl ring. For **1g** and **2g**, H′ and C′ refer to protons and carbons of 4-methoxy-substituted phenyl ring. Kinetic experiments were performed on a Beckman DU 650 UV–visible spectrophotometer.

Materials. Silica gel 60 (Merck, 0.06–0.2 mm) was used for column chromatography. The solvent MeOH[12] and the base solutions were purified and prepared as reported.

Compounds **1e**, **2e**,[13] **1f**, **2f**, **1k**, **2k**,[14] **1g**,[15] **1h**,[16] **1j**,[17] **1l** and **2l**[18] were prepared by published methods. For these compounds we now report the ^{13}C NMR δ values.

*1,1,1-Trichloro-2,2-bis(4,5-dimethoxy-2-methylphenyl)ethane (**1e**).* ^{13}C NMR, δ: 20.15 (2 CH_3); 55.51 (2 OCH_3); 55.84 (2 OCH_3); 59.84 (C-β); 103.62 (C-α); 112.65 (2 C-6); 113.36 (2 C-3); 128.29 (2 C-1); 129.77 (2 C-2); 146.34 and 147.88 (2 C-4 and 2 C-5).

*1,1-Dichloro-2,2-bis(4,5-dimethoxy-2-methylphenyl)ethene (**2e**).* ^{13}C NMR, δ: 19.57 (2 CH_3); 55.65 (2 OCH_3); 55.91 (2 OCH_3); 112.05 (2 C-6); 113.15 (2 C-3); 120.20 (C-α); 128.38 (2 C-2); 130.58 (2 C-1); 139.01 (C-β); 146.61 and 148.49 (2 C-4 and 2 C-5).

*1,1,1-Trichloro-2,2-bis(2,5-dimethoxyphenyl)ethane (**1f**).* ^{13}C NMR, δ: 52.12 (C-β); 55.55 (2 OCH_3); 56.62 (2 OCH_3); 102.15 (C-α); 112.32 (2 C-3); 112.64 (2 C-4); 116.46 (2 C-6); 128.33 (2 C-1); 152.00 (2 C-2); 152.98 (2 C-5).

*1,1-Dichloro-2,2-bis(2,5-dimethoxyphenyl)ethene (**2f**).* ^{13}C NMR, δ: 55.63 (2 OCH_3); 56.18 (2 OCH_3); 112.25 (2 C-3); 113.88 (2 C-4); 116.00 (2 C-6); 121.56 (C-α); 129.06 (2 C-1); 134.01 (C-β); 150.41 (2 C-2); 153.18 (2 C-5).

*1,1,1-Trichloro-2-(2-methoxyphenyl)-2-(4-methoxyphenyl)ethane (**1g**).* ^{13}C NMR, δ: 55.11 (OCH_3); 55.73 (OCH_3); 60.28 (C-β); 102.60 (C-α); 111.02 (C-3); 113.24 (C-3′,5′); 120.22 (C-5); 127.76 (C-1); 128.36 and 128.66 (C-4 and C-6); 129.84 (C-1′); 132.00 (C-2′,6′); 156.71 (C-2); 159.00 (C-4′).

*1,1,1-Trichloro-2,2-bis(2-methoxy-5-methylphenyl)ethane (**1h**).* ^{13}C NMR, δ: 20.94 (2 CH_3); 51.90 (C-β); 56.11 (2 OCH_3); 102.58 (C-α); 111.26 (2 C-3); 127.22 (2 C-1); 129.00 and 130.19 (2 C-4 and 2 C-6); 129.12 (2 C-5); 155.60 (2 C-2).

*1,1,1-Trichloro-2,2-bis(2,4-dimethoxyphenyl)ethane (**1j**).* ^{13}C NMR, δ: 51.33 (C-β); 55.17 (2 OCH_3); 55.87 (2 OCH_3); 98.74 (2 C-3); 103.27 (C-α); 104.05 (2 C-5); 120.36 (2 C-1); 130.14 (2 C-6); 158.65 (2 C-2); 159.98 (2 C-4).

*1,1,1-Trichloro-2,2-bis(3,4-dimethoxyphenyl)ethane (**1k**).* ^{13}C NMR, δ: 55.74 (2 OCH_3); 55.95 (2 OCH_3); 70.10 (C-β); 102.35 (C-α); 110.95 (2 C-5); 113.76 (2 C-

2); 122.48 (2 C-6); 130.85 (2 C-1); 148.56 and 148.82 (2 C-3 and 2 C-4).

*1,1-dichloro-2,2-bis(3,4-dimethoxyphenyl)ethene (**2k**).* ^{13}C NMR, δ: 55.65 (2 OCH_3); 55.76 (2 OCH_3); 110.46 (2 C-5); 112.50 (2 C-2); 117.77 (C-α); 122.19 (2 C-6); 131.89 (2 C-1); 139.81 (C-β); 148.24 and 148.57 (2 C-3 and 2 C-4).

*1,1,1-Trichloro-2,2-bis(4-methoxyphenyl)ethane (**1l**).* ^{13}C NMR, δ: 55.04 (2 OCH_3); 69.55 (C-β); 102.48 (C-α); 113.50 (2 C-3, 5); 130.46 (2 C-1); 131.00 (2 C-2, 6); 158.95 (2 C-4).

*1,1-Dichloro-2,2-bis(4-methoxyphenyl)ethene (**2l**).* ^{13}C NMR, δ: 55.18 (2 OCH_3); 113.47 (2 C-3, 5); 117.62 (C-α); 130.79 (2 C-2, 6); 132.03 (2 C-1); 139.66 (C-β); 159.11 (2 C-4).

*1,1,1-Trichloro-2-(4,5-dimethoxy-2-nitrophenyl)-2-(3,4-dimethoxyphenyl)ethane (**1a**).* A solution of **1k** (2.03 g, 5 mmol) in acetic anhydride (100 ml) was placed in a two-necked round-bottomed flask fitted with a mechanical stirrer and a reflux condenser protected by a $CaCl_2$ tube. $Cu(NO_3)_2{\cdot}3H_2O$ (0.604 g, 2.5 mmol) was added to the stirred solution. The mixture was heated at 40–50 °C for 0.5 h. The cold mixture was poured into water, then extracted with chloroform, neutralized, dried and evaporated *in vacuo*. Cristallization of the crude product from ethanol afforded pure **1a** as yellow crystals (yield 98%), m.p. 149 °C. ^{1}H NMR, δ: 3.88 (6H, s, 2 OCH_3); 3.93 (3H, s, OCH_3); 3.94 (3H, s, OCH_3); 6.28 (1H, s, H-β); 6.86 (1H, d, J_o = 8.4 Hz, H-5′); 7.18 (1H, d, J_m = 1.9 Hz, H-2′); 7.27 (1H, dd, J_o = 8.4 Hz, J_m = 1.9 Hz, H-6′); 7.47 (1H, s, H-6); 7.57 (1H, s, H-3). ^{13}C NMR, δ: 55.73 (OCH_3); 55.93 (OCH_3); 56.25 (2 OCH_3); 61.29 (C-β); 101.31 (C-α); 108.14 (C-3); 110.70 (C-5′); 112.32 (C-6); 113.84 (C-2′); 122.28 (C-6′); 126.44 (C-1); 129.04 (C-1′); 143.17 (C-2); 148.13, 148.54 and 148.93 (C-4, C-3′ and C-4′); 151.78 (C-5). HRMS (M^+), *m/z* calc. for $C_{18}H_{18}Cl_3NO_6$; 449.0200. Found: 449.0244.

*1,1,1-Trichloro-2-(4,5-dimethoxy-2-iodophenyl)-2-(3,4-dimethoxyphenyl)ethane (**1b**).* To a solution of **1k** (2.03 g, 5 mmol) in chloroform (30 ml) was added silver trifluoroacetate (1.10 g, 5 mmol). To this stirred mixture, a solution of iodine (1.27 g, 5 mmol) in chloroform (50 ml) was added dropwise. The mixture was left to stir overnight, then filtered to eliminate silver iodide and the resulting solution was poured into water. The aqueous layer was extracted twice with chloroform and the combined organic phase was neutralized, dried and evaporated *in vacuo*. The crude product was chromatographed over silica gel, employing light petroleum (b.p. 40–60 °C)–diethyl ether (80:20) as eluent, to give pure **1b** (yield 95%) as white crystals from 1:1 light petroleum (b.p. 40–60 °C)–diethyl ether, m.p. 84 °C. ^{1}H NMR, δ: 3.83 (3 H, s, OCH_3); 3.84 (3 H, s, OCH_3); 3.86 (3 H, s, OCH_3); 3.89 (3 H, s, OCH_3); 5.47 (1 H, s, H-β); 6.82 (1 H, d, J_o = 8.2 Hz, H-5′); 7.14 (1 H, d, J_m = 2.0 Hz, H-2′); 7.18 (1 H, dd, J_o = 8.2 Hz, J_m = 2.0 Hz, H-6′); 7.26 (1 H, s, H-3); 7.67 (1 H, s, H-6). ^{13}C NMR, δ: 55.61 (OCH_3); 55.80 (OCH_3); 55.85 (OCH_3); 55.88 (OCH_3); 71.98 (C-β); 91.79 (C-2); 102.11 (C-α); 110.47 (C-5′); 111.26 (C-6); 113.99 (C-2′); 121.84 (C-3); 122.99 (C-6′); 128.86 (C-1′); 133.38 (C-1); 148.16, 148.70, 148.78 and 148.83 (C-4, C-5, C-3′ and C-4′); HRMS (M^+), *m/z* calc. for $C_{18}H_{18}Cl_3IO_4$: 529.9315. Found: 529.9261.

*1,1,1-Trichloro-2-(2-bromo-4,5-dimethoxyphenyl)-2-(3,4-dimethoxyphenyl)ethane (**1c**).* A solution of **1k** (2.03 g, 5 mmol) in chloroform (10 ml) was stirred at room temperature during the dropwise addition of a solution of bromine (0.8 g, 5 mmol) in chloroform (10 ml). The solution was set aside at room temperature until the evolution of hydrogen bromine gas was complete (48 h). After solvent removal *in vacuo*, the crude product was chromatographed over silica gel, employing light petroleum (b.p. 40–60 °C)–diethyl ether (80:20) as eluent, to give pure **1c** (yield 85%) as white crystals from 1:1 light petroleum (b.p. 40–60 °C)–diethyl ether, m.p. 99 °C. ^{1}H NMR, δ: 3.85 (6 H, s, 2 OCH_3); 3.87 (3 H, s, OCH_3); 3.91 (3 H, s, OCH_3); 5.62 (1 H, s, H-β); 6.84 (1 H, d, J_o = 8.4 Hz, H-5′); 7.05 (1 H, s, H-3); 7.12 (1 H, d, J_m = 2.0 Hz, H-2′); 7.17 (1 H, dd, J_o = 8.4 Hz, J_m = 2.0 Hz, H-6′); 7.69 (1 H, s, H-6). ^{13}C NMR, δ: 55.67 (OCH_3); 55.87 (OCH_3); 55.95 (OCH_3); 56.05 (OCH_3); 67.16 (C-β); 101.96 (C-α); 110.56 (C-5′); 111.92 (C-6); 114.02 (C-2′); 115.56 (C-3); 116.29 (C-2); 123.02 (C-6′); 129.03 (C-1′); 129.97 (C-1); 148.01, 148.28, 148.80 and 148.91 (C-4, C-5, C-3′ and C-4′). HRMS (M^+), *m/z* calc. for $C_{18}H_{18}Cl_3BrO_4$: 481.9454. Found: 481.9503.

1,1,1-Trichloro-2-(3,4-dimethoxyphenyl)-2-ethanol. $LiAlH_4$ (1.14 g, 0.03 mol) was added to a suspension of 2,2,2-trichloro-3′,4′-dimethoxyacetophenone[19] (8.5 g, 0.03 mol) in anhydrous diethyl ether (75 ml) and after normal work-up 83% of 1,1,1-trichloro-2-(3,4-dimethoxyphenyl)-2-ethanol was obtained. The compound was recrystallized from ethanol, m.p. 135 °C. IR (Nujol), ν_{max}: 3420 cm^{-1} (OH). ^{1}H NMR, δ: 3.34 (1 H, d, J = 3.6 Hz, exchangeable with D_2O, OH); 3.90 (6 H, s, 2 OCH_3); 5.17 (1 H, d, J = 3.6 Hz, singlet after exchange with D_2O, $CHCCl_3$); 6.87 (1 H, d, J_o = 8.1 Hz, H-5); 7.14 (1H, dd, J_o = 8.1 Hz, J_m = 2.0 Hz, H-6); 7.17 (1 H, d, J_m = 2.0 Hz, H-2). HRMS (M^+), *m/z* calc. for $C_{10}H_{11}Cl_3O_3$: 283.9774. Found: 283.9802.

*1,1,1-Trichloro-2-(4,5-dimethoxy-2-methylphenyl)-2-(3,4-dimethoxyphenyl)ethane (**1d**).* A solution of 1,1,1-trichloro-2-(3,4-dimethoxyphenyl)-2-ethanol (6 g, 0.021 mol) in glacial acetic acid (50 ml) was added dropwise to a stirred solution of 3,4-dimethoxytoluene (3.20 g, 0.021 mol) in glacial acetic acid–98% sulphuric acid

(1:1, v/v) (10 ml), while the temperature was maintained below 20 °C. After standing at room temperature overnight, the mixture was poured on to crushed ice and the oil obtained was extracted with ethyl acetate, neutralized, dried and evaporated *in vacuo*. The oil obtained was chromatographed on silica gel, employing light petroleum (b.p. 40–60 °C)–ethyl acetate (80:20) as eluent, gave pure **1d** (yield 55%), as white crystals from 1:1 light petroleum ether (b.p. 40–60 °C)–diethyl ether, m.p. 83 °C. ^{1}H NMR, δ: 2.30 (3H, s, CH_3); 3.86 (9H, s, 3 OCH_3); 3.91 (3H, s, OCH_3); 5.20 (1H, s, H-β); 6.67 (1H, s, H-3); 6.82 (1H, d, J_o = 8.0 Hz, H-5′); 7.09 (1H, d, J_m = 2.0 Hz, H-2′); 7.11 (1H, dd, J_o = 8.0 Hz, J_m = 2.0 Hz, H-6′); 7.65 (1H, s, H-6). ^{13}C NMR, δ: 19.83 (CH_3); 55.62 (OCH_3); 55.70 (OCH_3); 55.86 (OCH_3); 56.10 (OCH_3); 64.87 (C-β); 102.71 (C-α); 110.47 (C-5′); 111.37 (C-6); 113.69 (C-3); 114.12 (C-2′); 123.50 (C-6′); 129.20 (C-2); 129.20 (C-1′); 129.58 (C-1); 146.61 (C-4); 147.91 (C-5); 148.24 and 148.66 (C-3′ and C-4′). HRMS (M^+), *m/z* calc. for $C_{19}H_{21}Cl_3O_4$: 418.0505. Found: 418.0544.

*1,1,1-Trichloro-2,2-bis(2,4,5-trimethoxyphenyl)ethane (**1i**).* To a stirred solution of 1,2,4-trimethoxybenzene (20.17 g, 0.12 mol) and chloral hydrate (4 g, 0.024 mol) in glacial acetic acid (50 ml), 98% sulphuric acid (30 ml) was added dropwise, while the temperature was maintained below 30 °C. After standing at room temperature overnight, the mixture was poured on to crushed ice and the precipitate obtained was filtered, neutralized and dried. Crystallization of the crude product from ethanol afforded **1i** as white crystals (yield 90%), m.p. 106 °C. ^{1}H NMR, δ: 3.82 (6H, s, 2 OCH_3); 3.84 (6 H, s, 2 OCH_3); 3.87 (6 H, s, 2 OCH_3); 6.34 (1 H, s, H-α); 6.53 (2 H, s, 2 H-3); 7.47 (2 H, s, 2 H-6). ^{13}C NMR, δ: 51.54 (C-β); 55.81 (2 OCH_3); 56.64 (2 OCH_3); 57.05 (2 OCH_3); 97.95 (2 C-3); 103.16 (C-α); 113.68 (2 C-6); 118.97 (2 C-1); 142.56 (2 C-5); 149.16 (2 C-4); 152.34 (2 C-2). HRMS (M^+), *m/z* calc. for $C_{20}H_{23}Cl_3O_6$: 464.0560. Found: 464.0514.

Reaction products. Compounds **1a–d** and **1g–j** (1 equiv.), were dehydrochlorinated by heating under reflux with a solution of CH_3ONa (2 equiv.) in dry CH_3OH. Reaction times for each compound are reported below. The crude dehydrohalogenated compounds **2a–d** and **2g–j** were purified by chromatography over silica gel employing mixtures of light petroleum (b.p. 40–60 °C)–ethyl acetate as eluents. The physical properties and spectral data for each compound are reported below.

*1,1-Dichloro-2-(4,5-dimethoxy-2-nitrophenyl)-2-(3,4-dimethoxyphenyl)ethene (**2a**).* Reaction time 48 h, yield 80%, yellow crystals from ethanol, m.p. 122 °C. ^{1}H NMR, δ: 3.85 (3 H, s, OCH_3); 3.86 (3 H, s, OCH_3); 3.97 (3 H, s, OCH_3); 3.99 (3 H, s, OCH_3); 6.78 (1 H, d, J_o = 8.4 Hz, H-5′); 6.81 (1 H, s, H-6); 6.85 (1 H, dd, J_o = 8.4 Hz, J_m = 2.0 Hz, H-6′); 7.07 (1H, d, J_m = 2.0 Hz, H-2′); 7.68 (1H, s, H-3). ^{13}C NMR, δ: 55.76 (OCH_3); 55.94 (OCH_3); 56.35 (OCH_3); 56.61 (OCH_3); 107.91 (C-3); 110.42 (C-5′); 112.59 (C-6); 113.02 (C-2′); 119.35 (C-α); 122.07 (C-6′); 128.98 and 129.26 (C-1 and C-1′); 136.72 (C-β); 139.80 (C-2); 148.28 and 148.64 (C-4 and C-3′); 149.12 (C-4′); 153.20 (C-5). HRMS (M^+), *m/z* calc. for $C_{18}H_{17}Cl_2NO_6$: 413.0433. Found: 413.0471.

*1,1-Dichloro-2-(4,5-dimethoxy-2-iodophenyl)-2-(3,4-dimethoxyphenyl)ethene (**2b**).* Reaction time 72 h, yield 50%, white crystals from ethanol, m.p. 143 °C. ^{1}H NMR, δ: 3.85 (3 H, s, OCH_3); 3.86 (3 H, s, OCH_3); 3.88 (6 H, s, 2 OCH_3); 6.72 (1 H, s, H-6); 6.81 (1 H, d, J_o = 8.4 Hz, H-5′); 6.95 (1 H, dd, J_o = 8.4 Hz, J_m = 2.0 Hz, H-6′); 7.08 (1H, d, J_m = 2.0 Hz, H-2′); 7.27 (1H, s, H-3). ^{13}C NMR, δ: 55.80 (OCH_3); 55.96 (OCH_3); 56.09 (OCH_3); 56.11 (OCH_3); 86.88 (C-2); 110.54 (C-5′); 112.39 (C-6); 112.99 (C-2′); 121.05 (C-α); 121.63 (C-3); 122.39 (C-6′); 129.47 (C-1′); 137.28 (C-1); 141.10 (C-β); 148.25, 148.97, 149.09 and 149.52 (C-4, C-5, C-3′ and C-4′). HRMS (M^+), *m/z* calc. for $C_{18}H_{17}Cl_2IO_4$: 493.9549. Found: 493.9450.

*1,1-Dichloro-2-(2-bromo-4,5-dimethoxyphenyl)-2-(3,4-dimethoxyphenyl)ethene (**2c**).* Reaction time 72 h, yield 60%, white crystals from ethanol, m.p. 133 °C. ^{1}H NMR, δ: 3.86 (6 H, s, 2 OCH_3); 3.88 (3 H, s, OCH_3); 3.89 (3H, s, OCH_3); 6.73 (1 H, s, H-6); 6.82 (1 H, d, J_o = 8.3 Hz, H-5′); 6.93 (1 H, dd, J_o = 8.3 Hz, J_m = 2.1 Hz, H-6′); 7.04 (1H, d, J_m = 2.1 Hz, H-2′); 7.07 (1H, s, H-3). ^{13}C NMR, δ: 55.80 (OCH_3); 55.90 (OCH_3); 56.00 (OCH_3); 56.10 (OCH_3); 110.46 (C-5′); 112.47 (C-2′); 112.59 (C-6); 113.25 (C-2); 115.46 (C-3); 121.00 (C-α); 122.01 (C-6′); 129.69 (C-1′); 132.73 (C-1); 138.61 (C-β); 148.19, 148.48, 148.81 and 149.23 (C-4, C-5, C-3′ and C-4′). HRMS (M^+), *m/z* calc. for $C_{18}H_{17}Cl_2BrO_4$: 445.9687. Found: 445.9732.

*1,1-Dichloro-2-(4,5-dimethoxy-2-methylphenyl)-2-(3,4-dimethoxyphenyl)ethene (**2d**).* Reaction time 72 h, yield 45%, white crystals from ethanol, m.p. 95 °C. ^{1}H NMR, δ: 2.17 (3 H, s, CH_3); 3.84 (3 H, s, OCH_3); 3.86 (3 H, s, OCH_3); 3.88 (3 H, s, OCH_3); 3.89 (3 H, s, OCH_3); 6.67 (1 H, s, H-3); 6.71 (1H, s, H-6); 6.80 (1 H, d, J_o = 8.4 Hz, H-5′); 6.88 (1 H, dd, J_o = 8.4 Hz, J_m = 1.9 Hz, H-6′); 6.96 (1H, d, J_m = 1.9 Hz, H-2′). ^{13}C NMR, δ: 19.08 (CH_3); 55.85 (2 OCH_3); 55.94 (2 OCH_3); 110.49 (C-5′); 112.08 (C-6); 112.45 (C-2′); 113.15 (C-3); 118.83 (C-α); 122.22 (C-6′); 128.29 (C-2); 130.58 (C-1′); 131.46 (C-1); 139.26 (C-β); 146.93 (C-5); 148.17, 148.54 and 148.69 (C-4, C-3′ and C-4′). HRMS (M^+), *m/z* calc. for $C_{19}H_{20}Cl_2O_4$: 382.0739. Found: 382.0700.

*1,1-Dichloro-2-(2-methoxyphenyl)-2-(4-methoxyphenyl)ethene (**2g**).* Reaction time 72 h, yield 48%, white crystals from 1:1 diethyl ether–light petroleum (b.p. 40–60 °C), m.p. 68 °C. ^{1}H NMR, δ: 3.77 (3 H, s, OCH_3); 3.79

(3 H, s, OCH_3); 6.84 (2 H, d, J_o = 8.7 Hz, H-3′,5′); 6.91 (1 H, d broad, J_o = 8.6 Hz, H-3); 6.96 (1H, t broad, J_o = 7.7 Hz, H-5); 7.18 (1 H, d broad, J_o = 7.2 Hz, H-6); 7.29 (2 H, d, J_o = 8.7 Hz, H-2′,6′); 7.31 (1 H, t broad, H-4). ^{13}C NMR, δ: 55.15 (OCH_3); 55.64 (OCH_3); 111.48 (C-3); 113.28 (C-3′, 5′); 119.35 (C-α); 120.55 (C-5); 129.29 (C-1); 129.48 and 130.04 (C-4 and C-6); 130.20 (C-2′, 6′); 131.12 (C-1′); 137.02 (C-*β*); 156.18 (C-2); 158.91 (C-4). HRMS (M^+), *m/z* calc. for $C_{16}H_{14}Cl_2O_2$: 308.0370. Found: 308.0340.

*1,1-Dichloro-2,2-bis(2-methoxy-5-methylphenyl)-ethene (**2h**).* Reaction time 96 h, yield 45%, white crystals from ethanol, m.p. 113 °C. ^{1}H NMR, δ: 2.28 (6 H, s, 2 CH_3); 3.84 (6 H, s, 2 OCH_3); 6.82 (2 H, d, J_o = 8.3 Hz, 2 H-3); 7.07 (2 H, d, J_o = 8.3 Hz, 2 H-4); 7.09 (2 H, s, 2 H-6). ^{13}C NMR, δ: 20.45 (2 CH_3); 55.81 (2 OCH_3); 111.28 (2 C-3); 120.96 (C-α); 128.42 (2 C-1); 129.58 (2 C-5); 129.58 and 130.54 (2 C-4 and 2 C-6); 134.17 (C-*β*); 154.10 (2 C-2). HRMS (M^+), *m/z* calc. for $C_{18}H_{18}Cl_2O_2$: 336.0684. Found: 336.0649.

*1,1-Dichloro-2,2-bis(2,4,5-trimethoxyphenyl)ethene (**2i**).* Reaction time 96 h, yield 60%, white crystals from ethanol, m.p. 122 °C. ^{1}H NMR, δ: 3.75 (6 H, s, 2 OCH_3); 3.82 (6 H, s, 2 OCH_3); 3.86 (6 H, s, 2 OCH_3); 6.49 (2 H, s, 2 H-3); 6.83 (2 H, s, 2 H-6). ^{13}C NMR, δ: 55.73 (2 OCH_3); 56.35 (4 OCH_3); 97.49 (2 C-3); 113.75 (2 C-6); 119.76 (2 C-1); 121.05 (C-α); 134.06 (C-*β*); 142.51 (2 C-5); 149.30 (2 C-4); 150.42 (2 C-2). HRMS (M^+), *m/z* calc. for $C_{20}H_{22}Cl_2O_6$: 428.0793. Found: 428.0833.

*1,1-Dichloro-2,2-bis(2,4-dimethoxyphenyl)ethene (**2j**).* Reaction time 96 h, yield 45% white crystals from ethanol, m.p. 129 °C. ^{1}H NMR, δ: 3.77 (6 H, s, 2 OCH_3); 3.78 (6 H, s, 2 OCH_3); 6.43 (2 H, d, J_m = 2.3 Hz, 2 H-3); 6.45 (2 H, dd, J_o = 8.9 Hz, J_m = 2.3 Hz, 2 H-5); 7.15 (2 H, d, J_o = 8.9 Hz, 2 H-6). ^{13}C NMR, δ: 55.28 (2 OCH_3); 55.54 (2 OCH_3); 98.66 (2 C-3); 104.18 (2 C-5); 120.83 (C-α); 121.44 (2 C-1); 130.75 (2 C-6); 134.03 (C-*β*); 157.27 (2 C-2); 160.52 (2 C-4). HRMS (M^+), *m/z* calc. for $C_{18}H_{18}Cl_2O_4$: 368.0582. Found: 368.0545.

Kinetics. Reaction mixtures for kinetic measurements were prepared by mixing thermostated volumes of base and substrate solutions. The substrate concentrations used were 5×10^{-5}–1×10^{-4} M. Reactions mixtures were placed in cuvettes that had been temperature equilibrated for at least 15 min. The kinetics were studied by following spectrophotometrically the appearance of the reaction products at a wavelength where the largest difference between the absorbance spectra of the reagents and products was observed (**1a**, 296; **1b**, 299; **1c**, 301; **1d**, 297; **1e**, 300; **1g**, 290; **1h**, 290; **1i**, 292; **1l**, 290 nm).

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