THE EFFECT OF PHENYL SUBSTITUENTS ON ELIMINATION STEREOCHEMISTRY: A MECHANISTIC MANIFOLD IN ALKOXIDE PROMOTED DECOMPOSITION OF 1-PHENYL-1-PROPYLTRIMETHYLAMMONIUM ION*

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Received October 3rd, 1980

Reactions of the positionally isomeric 1-phenyl-1-propyl (*I*) and 1-phenyl-2-propyltrimethylammonium (*II*) ions with CH_3OK–CH_3OH, t-C_4H_9OK–t-C_4H_9OH and t-C_4H_9OK–C_6H_6 systems have been investigated with aid of the deuterated analogues *erythro*-2-D-*I*, *threo*-2-D-*I*, 1-D-*I* and *threo*-1-D-*II*. At least five mechanistic components (*anti*-β-elimination, *syn*-β-elimination, α′,β-elimination, Sommelet–Hauser rearrangement and S_N2 substitution) have been found to participate in the reaction of the quaternary compound *I*, in proportions varying greatly with base–solvent combination. The corresponding reactions of the isomeric compound *II* proceeded in a more simple manner, without the intervention of ylide pathways in the olefin as well as in the amine formation. The stereochemistry of β-elimination determined for the two phenyl-substituted 'onium compounds has been compared with that reported previously for structurally related aliphatic analogues. The "anomalously" low propensity for *syn*-elimination as well as the "anomalously" high values of *trans*/*cis*-olefin ratios in *anti*-elimination stigmatizing the presence of phenyl substituents are proposed to originate from a lack of base-approach hindrance in the reaction.

Steric substituent effects in E2 reactions have been studied during the past decade and their intricate role in the *syn-anti* competition has been gradually[1–5] resolved. In a contrast, electronic substituent effects upon the stereochemical competition have remained uncertain[4,6]. It is generally expected that electronic effects can alter elimination stereochemistry by inducing changes in the scale of variable transition states[7]. The previously established correlation between the electron-donating properties of the participating base[1,8] and/or the electron-withdrawing properties of leaving group[9,10] on one side and the *syn*/*anti* ratios in bimolecular elimination on the other has been interpreted[1,7] to result from a shift to "a more reactant-like" side of the transition state scale where the intrinsic preferences for *anti*-elimination are weaker.

* Part XLII in the series Elimination Reactions; Part XLI: This Journal *45*, 3150 (1980)

Evidence[11,12] that electronic influences of α- and β-placed phenyl substituents also induce a shift to the reactant-like side of the transition state scale in eliminations from alkyltrimethylammonium ions prompted us to investigate the accompanying effect of the phenyl substituents on the stereochemical course. In this paper, we have determined the contributions of *syn*- and *anti*-pathways to *trans*- and *cis*-1-phenyl--1-propene (*trans*- and *cis-III*) formation in the reaction of 1-phenyl-1-propyl and 1-phenyl-2-propyltrimethylammonium ions (*I* and *II*; $X = \overset{(+)}{N}(CH_3)_3$) with three different base–solvent systems and compared the results with those reported previously by Bailey and Saunders[1] for *trans*- and *cis*-2-hexene (*trans*- and *cis-VI*) formation from the corresponding n-propyl substituted trimethylammonium ions (*IV* and *V*, respectively; $X = \overset{(+)}{N}(CH_3)_3$).

$C_6H_5CHXCH_2CH_3$ — *I*

$C_6H_5CH_2CHXCH_3$ — *II*

$C_6H_5CH{=}CHCH_3$ — *trans*- and *cis-III*

$n\text{-}C_3H_7CHXCH_2CH_3$ — *IV*

$n\text{-}C_3H_7CH_2CHXCH_3$ — *V*

$n\text{-}C_3H_7CH{=}CHCH_3$ — *trans*- and *cis-VI*

For the stereochemical determination we employed, as in previous studies[1,13,14], the stereospecifically β-deuterium labelled derivatives, *erythro*- and *threo*-2-D-*I* ($X = \overset{(+)}{N}(CH_3)_3\overset{(-)}{Cl}$) and *threo*-1-D-*II* ($X = \overset{(+)}{N}(CH_3)_3\overset{(-)}{Cl}$). The deuterium labelled derivatives of *I*, *erythro*- and *threo*-2-D-*I*, were synthetized from *cis*- and *trans*--1-phenyl-1-propene, *cis*- and *trans-III*, respectively. Deuterioboration of the *cis*--olefin followed by amination with NH_2Cl and by the Clarke–Eschweiler methylation gave two position isomeric dimethylamines, *erythro*-2-D-I and *erythro*-1-D-*II* ($X = N(CH_3)_2$), in ratio 94 : 6. Analogous reaction sequence starting with the *trans*--olefin gave another position isomeric pair of dimethylamines, *threo*-2-D-*I* and *threo*--1-D-*II* ($X = N(CH_3)_2$), in a very similar ratio 95 : 5. Separation of the two above mixtures by preparative gas chromatography afforded pure amines *erythro*- and *threo*-2-D-*I* which were converted into the corresponding methochlorides by standard procedures[6] in quantitative yields.

Reduction of *trans*-1-phenyl-1,2-epoxypropane with lithium aluminium deuteride–aluminium chloride[15] (6 : 1) gave a mixture of the positionally isomeric alcohols *erythro*-2-D-*I* and *erythro*-1-D-*II* (X = OH) in ratio 3 : 97 which on treatment with *p*-toluenesulphonyl chloride in pyridine and crystallisation afforded the pure tosyloxy derivative of the prevailing isomer *erythro*-1-D-*II* (X = OTs). The tosyloxy deriva-

tive was converted (with inversion of configuration) into the quaternary salt *threo*-1-D-*II* ($X = \overset{(+)}{N}(CH_3)_3\overset{(-)}{Cl}$) by reaction with sodium azide in dimethyl sulphoxide followed by lithium aluminium hydride reduction and quaternisation. Attempts to synthetize the other diastereoisomer, *erythro*-1-D-*II* ($X = \overset{(+)}{N}(CH_3)_3\overset{(-)}{Cl}$) analogously from *cis*-1-phenyl-1,2-epoxypropane surprisingly failed because the epoxide ring opening afforded a mixture of two positionally isomeric alcohols (*threo*-2-D-*I* and *threo*-1-D-*II*; X = OH) in which the requisite isomer *threo*-1-D-*II* was present only as a minor product (10 : 90).

EXPERIMENTAL

1-Phenyl-1-dimethylaminopropane

A mixture of 1-phenyl-1-aminopropane[16] (5·5 g; 40 mmol), formic acid (100 ml) and 38% aqueous formaldehyde (100 ml) was refluxed for 24 h. A usual work-up afforded 5·5 g (84%) of the product, b.p. 78—80°C/1·33 kPa. For $C_{11}H_{17}N$ (163·3) calculated: 80·93% C, 10·50% H, 8·58% N; found: 81·10% C, 10·63% H, 8·45% N.

Methoiodide: The above amine was treated with an excess of methyl iodide in ether. After 4 days standing in the dark the deposited crystals were filtered off and recrystallised from ethanol–ether. Yield 99%; m.p. 162—163·5°C (lit.[16] 162·5°C).

1-Phenyl-2-dimethylaminopropane

Prepared analogously as the positional isomer from 1-phenyl-2-aminopropane[17]. Yield 91%; b.p. 123—124°C/5·3 kPa. For $C_{11}H_{17}N$ (163·3) calculated: 80·93% C, 10·50% H, 8·58% N; found: 80·81% C, 10·23% H, 8·63% N.

Methoiodide: A treatment of the amine with an excess of methyl iodide in ether, followed by recrystallisation from ethanol afforded the product in 95% yield; m.p. 233—235°C (lit.[17] 228—230°C).

threo-1-Phenyl-1-dimethylamino-(2-^{2}H)propane

A stirred solution of *trans*-1-phenylpropene[18] (18·8 g; 0·159 mol) and of sodium borodeuteride (2·22 g; 0·053 mol) in dry diglyme (150 ml) was treated under nitrogen at 0°C with boron trifluoride etherate (10 g; 0·07 mol) in the course of 30 min and the mixture kept under these conditions for 5 h. It was then treated at 0°C with water (7·5 ml), 3M-NaOH (50 ml), 10M-NH_4OH (16·2 ml) followed by 1M solution of sodium hypochlorite (165 ml). After stirring for 1·5 h at 20°C, the mixture was diluted with water (900 ml), made alkaline with sodium hydroxide solution and extracted repeatedly with ether. The ethereal extracts were washed with water, dried over KOH pellets and the solvent taken down. The residue was treated with formic acid and formaldehyde under conditions described for the unlabelled analogue. It was obtained 12 g (46%) of a mixture consisting of the title amine (94·6%) and of the positional isomer, *threo*-(1-^{2}H)-1-phenyl-2-dimethylaminopropane; 5·4%). The title amine was separated by preparative gas chromatography; according to mass spectrometry, the product contained 6·6% of the d_0 and 93·4% of the d_1 species.

erythro-1-Phenyl-1-dimethylamino-(2-^{2}H)propane

Deuterioboration of *cis*-1-phenylpropene[19], followed by the amination and the Clarke–Eschweiler methylation under the same conditions as described above for the *threo*-isomer afforded in 56% yield a mixture of the title amine (93·5%) and of the positional isomer, *erythro*-(1-^{2}H)-1--phenyl-2-dimethylaminopropane; 6·5%. The main product was isolated by preparative gas chromatography; it contained 6·3% of the d_0 and 93·7% of the d_1 species.

erythro-(1-^{2}H)-1-Phenyl-2-propanol

A solution of lithium aluminium deuteride (8·9 g; 0·21 mol) in ether (300 ml) was treated under stirring and ice-cooling with a solution of anhydrous aluminium chloride (4·72 g; 0·0354 mol) in ether (50 ml), followed by a solution of *trans*-1,2-epoxy-1-phenylpropane[20] (14·2 g; 0·106 mol) in ether (150 ml). The mixture was refluxed for 5 h and decomposed by water and 3M-HCl. It was isolated 13·8 g (95·5%) of the title product contamined with 3·5% of the positional isomer, *erythro*-(2-^{2}H)-1-phenyl-1-propanol. The impurity was separated by a crystallisation of the *p*-toluenesulphonate, prepared from the alcohol and *p*-toluenesulphonyl chloride in pyridine. Usual work-up followed by crystallisation from petroleum ether afforded the product in 76% yield; m.p. 90—92°C.

threo-(1-^{2}H)-1-Phenyl-2-dimethylaminopropane

A solution of the above *erythro*-1-D-labelled *p*-toluenesulphonate (20·5 g; 0·07 mol) and of sodium azide (23 g; 0·354 mol) in dimethyl sulphoxide (280 ml) was heated under stirring to 80 to 90°C for 5 h. The cold mixture was diluted water (3 l) and the azido derivative taken up in ether. The ethereal layer was washed with water, dried with magnesium sulphate and treated with 0·71M solution of lithium aluminium hydride in ether (200 ml) under reflux (4 h). Usual work-up afforded *threo*-(1-^{2}H)-1-phenyl-2-aminopropane in nearly quantitative yield. The Clarke–Eschweiler methylation of the amine was performed under the same conditions as described above for the unlabelled analogue. It was obtained 9·9 g (88%) of the title product which contained 2·9% of the d_0 and 97·1% of the d_1 species.

(1-^{2}H)-1-Phenyl-1-propanol

Propiophenone (27·1 g; 0·20 mol) was reduced with lithium aluminium deuteride (3·9 g; 0·092 mol) in ether (320 ml). Yield 23·5 g (85%): b.p. 88°C/1·4 kPa.

p-*Toluenesulphonate*: A solution of the above alcohol (18 g; 0·131 mol) in ether (100 ml) was treated at —10°C with 1·31M solution of propyllithium (100 ml) in ether, followed by a solution of *p*-toluenesulphonyl chloride (25 g; 0·131 mol) in ether (250 ml). After additional stirring for 5 h at —5°C the mixture was decomposed by water and worked-up in a usual manner. The product was obtained as an oil in 90% yield.

(1-^{2}H)-1-Phenyl-1-dimethylaminopropane

Prepared from (1-^{2}H)-1-phenyl-1-propyl *p*-toluenesulphonate in the same manner as described for the *threo*-(1-^{2}H)-1-phenyl-2-propyl isomer. The product contained 1·5% of the d_0 and 98·5% of the d_1 species.

Deuterium Labelled Quaternary Salts

Quaternary iodides were prepared from the corresponding dimethylamines under conditions described above for the unlabelled salts. Quaternary chlorides were prepared from the iodides by shaking with silver chloride in methanol; before use were dried *in vacuo* at 65°C/0·13 kPa for 5 h.

Deuterium Labelled Amine Oxides

Prepared from the corresponding dimethylamines by treatment with 30% hydrogen peroxide under standard conditions[21]. The Cope elimination of the amine oxides was performed in tert-butanol under conditions reported previously[21].

Elimination Runs

The conditions used in the alkoxide-promoted reactions are summarised in Table I. The reactions were invariably carried out under nitrogen in sealed tubes. After completed heating, the ampoules were cooled to —60°C and, where convenient, stored at this temperature.

Determination of product composition: The contents of the ampoule were transferred into a separatory funnel, diluted with a ten-fold amount of 3M-NaOH and the products taken up in pentane. A sample of the pentane layer was injected into gas chromatograph.

Isolation of olefins: The pentane extract was washed with 1M hydrochloric acid and water, dried with magnesium sulphate and the solvent taken down through a short column. The residue was distilled and/or separated by preparative gas-chromatography.

Isolation of amines: Trimethylamine hydrochloride was isolated by the procedure described previously[14]. The other amines were isolated from the acid aqueous layer (*vide supra*) by basification with KOH pellets and extraction with ether. After a usual work-up, the amines were distilled and/or separated by preparative gas-chromatography.

1-((2'-^{2}H)-1'-Propyl)-2-dimethylaminomethylbenzene

Distillation of the basic fraction from the reaction of the quaternary chloride *threo*-2-D-*I* (2·4 g; 0·011 mol) with 0·4M t-C_4H_9OK in benzene (90 ml) yielded 0·8 g (40%) of an oil, b.p. 100 to 101°C/21·3 kPa. ^{1}H-NMR spectrum (Varian HA—100, $CDCl_3$; hexamethyldisilane; (ppm; J(Hz): CH_3—CHD— (0·93; d; 3 H; $J_{CH_3,CH}$ 7·0); CH_3—CHD—CH_2— (1·54; m; 1 H); $N(CH_3)_2$ (2·20; s, 6 H); Ar—CH_2—CHD— (2·64; bd; 2 H; $J_{CH_2,CH}$ 7·5); ArCH_2—N— (3·36; s; 2 H); C_6H_4 (6·90—7·30; m; 4 H). Mass spectrum: $M^{(+)}$ = 178. For $C_{12}H_{18}DN$ (178·3) calculated: 80·90% C, 11·25% H(D); 7·85% N; found: 81·08% C, 10·98% H(D), 7·95% N.

Control Experiments

Configurational stability of the labelled reactants. The α-labelled quaternary chloride 1-D-*I* was decomposed under conditions of elimination runs. Mass-spectroscopy of the products showed (Table II) a complete retention of the deuterium label in CH_3OK/CH_3OH and t-C_4H_9.OK/ /t-C_4H_9OH systems indicating that no isotope exchange in the α-position of substrate took place in course of the reaction. A non-negligible loss of the deuterium label was found in t-C_4H_9OK/C_6H_6 system.

Mass spectroscopy of the dimethylamines isolated from the reaction of the labelled substrates *erythro*-2-D-*I*, *threo*-2-D-*I* and *threo*-1-D-*II* showed a complete retention of deuterium, regardless of the base–solvent system employed. It indicates that no isotope exchange in β-position of the substrates took place in course of the reaction.

The dimethylamines *erythro*- and *threo*-2-D-*I* (X = $N(CH_3)_2$) recovered from the t-C_4H_9OK/t-C_4H_9OH promoted reaction of the corresponding quaternary salts (*erythro*- and *threo*-2-D-*I*; X = $N^{(+)}(CH_3)_3$, respectively) were converted into amine oxides by a treatment with 30% hydrogen peroxide. The Cope elimination of the amine oxide *erythro*-2-D-*I*; X = $N(CH_3)_2O$, yielded a practically pure olefin *trans-III* which contained 98·8% of the d_1 species originally present in the starting trimethylammonium ion. Conversely, the Cope elimination of the amine oxide *threo*-2-D-*I*; X = $N(CH_3)_2O$, yielded *trans-III* alkene which contained only 2·3% of the d_1 label from the starting trimethylammonium ion. Since Cope elimination is known to be a clean

TABLE I
Reaction Conditions

Base/Solvent	Concentration, mol/l		Temperature °C	Time h
	base	substrate		
CH_3OK/CH_3OH	2·0	0·15	120	5
t-C_4H_9OK/t-C_4H_9OH	0·6	0·15	55	5
t-C_4H_9OK/C_6H_6	0·3	0·10	25	0·1

TABLE II
Elimination from 1-Phenyl-(1-^{2}H)propyltrimethylammonium Ion: Deuterium Contents in Products

Base/Solvent	Percentage[a] of d_1	
	olefins[b]	amines
CH_3OK/CH_3OH	100	100[c]
t-C_4H_9OK/t-C_4H_9OH	100	99[c]
t-C_4H_9OK/C_6H_6	95	89[d]

[a] Corrected for incomplete labelling of the reactant. [b] In the resulting mixture of *trans*- and *cis-III*. [c] In the dimethylamine *I*; X = $N(CH_3)_2$. [d] In the dimethylamine *VIII*; *cf.* Table III. The amine *VIII* contained also about 2% of the d_2 species. The trimethylamine resulting in the reaction with t-C_4H_9OK/C_6H_6 system contained about 2% of the d_1 species.

syn-elimination[22,23], the results indicate that the starting onium compounds almost completely retains configuration in course of the base-promoted reaction.

Configurational stability of products: *cis*-1-Phenyl-1-propene (*cis-III*) remained practically (>95%) unchanged on treatment with CH_3OK/CH_3OH, t-C_4H_9OK/t-C_4H_9OH and t-C_4H_9OK/C_6H_6 systems under conditions of the elimination runs. However, about 20% isomerisation to the more stable isomer *trans-III* took place in the latter two base–solvent systems in the presence of an "inert" tetraalkylammonium ion[24] (cyclohexyltrimethylammonium chloride; in concentration comparable with that employed for the 'onium compounds *I* and *II* in Table I). This may be taken as an upper limit for isomerisation during the elimination runs; the actual extent of isomerisation is expected to be smaller because the base-catalyzed decomposition of the "inert" cyclohexyltrimethylammonium ion is presumably much slower than that of the phenyl-activated ions *I* and *II*. In any case, the isomerisation cannot obscure significantly the elimination stereochemistry in *trans-III* alkene formation; the unstable *cis-III* isomer represented always only a minor part (less than 10%) in the overall olefin-forming reaction (*vide infra*; Table III).

trans-1-Phenyl-1-propene (*trans-III*) does not isomerise under the conditions of elimination runs in the absence as well as in the presence of cyclohexyltrimethylammonium ion. The complementary evidence that the prevailing part of deuterium label has been retained in the olefin formation from 1-D-*I* (Table II) as well as from *threo*-1-D-*II* (*vide infra*; Table IV), irrespective of base–solvent system, excludes that an "invisible" isomerisation of *trans-III* took place in course of the elimination reaction.

1-Phenyl-3-propene (*VII*) isomerisation to *trans*- and *cis-III* is known[25] to be extremely fast; the eventual formation of the unstable isomer from the quaternary salts *II* and *threo*-1-D-*II* might therefore easily escape detection in the elimination runs. However, the complementary evidence that practically all the deuterium label is retained in the *trans-III* alkene formation from *threo*-1-D-*II* (*vide infra*; Table IV) speaks strongly against this remote possibility.

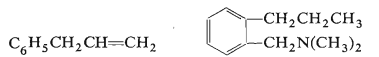
Gas chromatography: The phenylpropenes *trans-III*, *cis-III* and *VII* were separated (both analytically as well as preparatively) using a Chromosorb column impregnated with polybutyleneadipate (3%) and tetrakis-β-cyanethoxyerythritol (3%). The amines *I*, *II* and *VIII* (X = $N(CH_3)_2$ were separated using polyethylene glycol (10%) on the porous tile support pre-treated with potassium hydroxide.

RESULTS

Product composition data from the reaction of the quaternary salts *I* and *II* with the three base–solvent systems investigated are summarized in Table III. The elimination component of the overall reaction gave always a mixture of two isomeric olefins, *trans-III* and *cis-III*. The positionally isomeric olefin *VII*, which may arise only from *II* has been found in negligible (<0·1%) amounts.

The olefin formation was accompanied by several basic products. In addition to trimethylamine – a by-product of elimination – 1-phenyl-1-dimethylaminopropane (*I*; X = $N(CH_3)_2$) and 1-phenyl-2-dimethylaminopropane (*II*; X = $\overset{(+)}{N}(CH_3)_2$) arose from the corresponding quaternary salts (*I* and *II*; X = $N(CH_3)_3$, respectively) in a concurring S_N2 reaction. Moreover, another dimethylamine arose simultaneously from the reaction of *I* with t-C_4H_9OK/t-C_4H_9OH and particularly

with t-C_4H_9OK/C_6H_6 systems. On basis of ^{1}H-NMR and mass spectra and elemental analysis the amine was assigned the structure of 1-propyl-2-dimethylaminomethylbenzene (*VIII*).



VII *VIII*

TABLE III
Product Composition Data

Reactant	Base/solvent	Olefins		Amines	
		% overall[a]	% *trans-III*	% overall[b]	% *VIII*
I	CH_3OK/CH_3OH	55	94·5	45	0
I	t-C_4H_9OK/t-C_4H_9OH	35	90·4	65	5
I	t-C_4H_9OK/C_6H_6	30	97·3	70	98
II	CH_3OK/CH_3OH	80	95·9	20	0
II	t-C_4H_9OK/t-C_4H_9OH	90	93·8	10	0
II	t-C_4H_9OK/C_6H_6	95	97·3	5	0

[a] A mixture of *trans*- and *cis-III*. [b] A mixture of *I* (or *II*); X = $N(CH_3)_2$ and *VIII*.

TABLE IV
Deuterium Isotope Composition Data from Elimination of β-Labelled Substrates

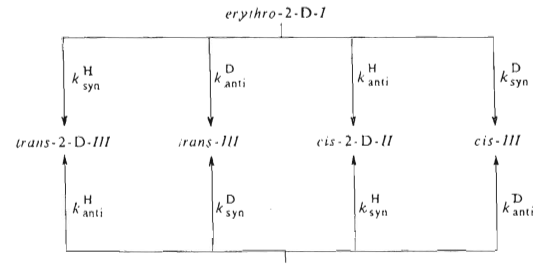
Reactant	Base/solvent	% d_1 in *trans-III*[a,b]	% d_1 in *cis-III*[a,b]
threo-2-D-*I*	CH_3OK/CH_3OH	99·8	—[c]
erythro-2-D-*I*		9·3	96·6
threo-I-D-*II*		97·7	—[c]
threo-2-D-*I*	t-C_4H_9OK/t-C_4H_9OH	85·7	—[c]
erythro-2-D-*I*		62·0	97·6
threo-1-D-*II*		95·0	—[c]
threo-2-D-*I*	t-C_4H_9OK/C_6H_6	79·3	—[c]
erythro-2-D-*I*		88·8	—[c]
threo-1-D-*II*		97·5	—[c]

[a] Corrected for incomplete labelling in the starting quaternary salt. [b] % d_0 + % d_1 = 100; the percentage of the d_2 species was invariably negligibly small. [c] Not determined.

Information concerning the steric course of elimination (*anti- vs syn-*) from the quaternary salts *I* and *II* has been obtained with aid of the β-stereospecifically deuterium labelled derivatives *erythro*-2-D-*I*, *threo*-2-D-*I* and *threo*-2-D-*II*. As it follows from the configurational correlation between reactant and product exemplified for the reaction of *erythro*- and *threo*-2-D-*I* in Scheme 1, the elimination can give rise to a four-component mixture of the isotope isomers (*e.g.*, *trans*-2-D-*III*, *trans-III* *cis*-2-D-*III* and *cis-III*), in which proportions of the individual isomers correspond to the contributions of the individual elimination pathways.

The procedure employed for the stereochemical assessment consisted of gas-chromatographic separation of the resulting olefinic mixtures into the *trans*- and *cis*-fractions followed by mass-spectroscopic determination of deuterium contents in the separated isomers. The results are summarized in Table IV.

A very marked operation of the kinetic hydrogen isotope effect is immediately apparent from the data in Table IV. Thus, the reaction of *threo*-2-D-*I* with CH_3OK/ /CH_3OH gave *trans-III* alkene which contained 99·8% of the d_1 species indicating (Scheme 1) that only 0·2% of the olefin arose by *syn*-elimination whereas the pre-



SCHEME 1

dominant part (99·8%) was formed by *anti*-elimination. However, the corresponding reaction of *erythro*-2-D-*I* gave *trans*-alkene which contained 9·3% of the d_1 species indicating that 9·3% of the reaction took place by *syn*-elimination and 90·7% by *anti*-elimination. Analogous differences are observed also with the other base–solvent systems. A correction on the operation of the isotope effect has been therefore made allowing to evaluate approximately the contributions of the *anti*- and *syn*-elimination pathways in the reaction of the parent, unlabelled, reactants (%(*anti*-H) and %(*syn*-H), respectively). Following the procedure employed earlier by Bailey and Saunders[1], we have used equations (*1*)–(*4*) in the calculation:

$$\% (syn\text{-H})^{trans} = \left(\frac{2{\cdot}2\%\, d_0\, (100)}{2{\cdot}2\%\, d_0 + \%\, d_1} \right)^{threo}, \qquad (1)$$

$$\% (syn\text{-H})^{trans} = \left(\frac{0{\cdot}33\%\, d_1\, (100)}{0{\cdot}33\%\, d_1 + \%\, d_0} \right)^{erythro}, \qquad (2)$$

$$\% (syn\text{-H})^{cis} = \left(\frac{2{\cdot}2\%\, d_0\, (100)}{2{\cdot}2\%\, d_0 + \%\, d_1} \right)^{erythro}, \qquad (3)$$

$$\% (syn\text{-H}) + \% (anti\text{-H}) = 100\,, \qquad (4)$$

where $\% (syn\text{-H})^{trans}$ and $\% (syn\text{-H})^{cis}$ are the corrected contributions of *syn*-elimination to the formation of *trans*- and *cis*-olefin, respectively, and $\% d_0$ and $\% d_1$ are the corresponding mass-spectroscopic data from Table IV. The results of the calculation are summarized in Table V. While earlier evidence[11,12,26,27] allow us to assume that the *anti*-elimination from the quaternary salts *I* and *II* proceeds uniformly by a one-step β-mechanism, both the one-step (β) as well as two-step (α',β)-mechanisms must be considered for the *syn*-elimination. The operation of the two-step α',β (ylide) mechanism has been ascertained from the contents of the d_1 species present in the trimethylamine set free in the elimination from the *threo*-2-D-*I* and *threo*-1-D-*II* labelled reactants. The contributions of the ylide mechanism found in the reaction of the *threo*-2-D-*I* compound are summarized in Table VI. No d_1 species were found in the

TABLE V

Approximate Contributions of *anti*- and *syn*-Elimination to 1-Phenyl-1-Propene (*trans*- and *cis-III*) Formation from the Quaternary Salts *I* and *II*

Substrate	Base/solvent	*trans-III*		*cis-III*	
		% *syn*[a]	% *anti*	% *syn*[a]	% *anti*
I	CH_3OK/CH_3OH	1·8[b]	98·2[c]	7·1[d]	92·9[d]
I	$t\text{-}C_4H_9OK/t\text{-}C_4H_9OH$	31·0[b]	69·0[c]	5·1[d]	94·1[d]
I	$t\text{-}C_4H_9OK/C_6H_6$	54·5[b]	45·5[c]	—[e]	—[e]
II	CH_3OK/CH_3OH	4·9[f]	95·1[c]	—[e]	—[e]
II	$t\text{-}C_4H_9OK/t\text{-}C_4H_9OH$	10·3[f]	89·7[c]	—[e]	—[e]
II	$t\text{-}C_4H_9OK/C_6H_6$	5·3[f]	94·7[c]	—[e]	—[e]

[a] The overall contribution of the β- and α',β-mechanisms. [b] Average of the values calculated from Eqs (*1*) and (*2*). [c] Calculated from Eq. (*4*). [d] Calculated from Eq. (*3*). [e] Not determined. [f] Calculated from Eq. (*1*).

trimethylamine set free from the positionally isomeric reactant *threo*-1-D-*II* indicating in accord with the data in Table IV, absence of the ylide mechanism in the reaction.

Operation of other two-step mechanisms, α- and $(E_1cB)_{revers.}$, in the alkoxide-promoted reactions from *I* as well as *II* has been satisfactorily excluded by the control experiments described in the Experimental.

TABLE VI

Ylide Mechanism in Olefin Formation from the Quaternary Salt *threo*-2-D-*I* in Different Base/Solvent Systems

Base/solvent	% d_1 in $N(CH_3)_3$	% *syn*-Elim. overall[a]	% Ylide in *syn*-elim.
CH_3OK/CH_3OH	0·0	0·2	0
t-C_4H_9OK/t-C_4H_9OH	2·8	14·3	19
t-C_4H_9OK/C_6H_6	15·3	20·7	74

[a] Calculated from the data in Table IV.

TABLE VII

Substituent Effect on *syn-anti* Competition: A Comparison of Phenyl *vs* n-Propyl Group

R^α	R^β	CH_3OK/CH_3OH % *syn*[a] in	t-C_4H_9OK/-C_4H_9OH % *syn*[a] in
C_6H_5	CH_3	2[b]	31[b] (25)[c]
n-C_3H_7	CH_3	10[d,e]	70[d,f]
CH_3	C_6H_5	5[b]	10[b]
CH_3	n-C_3H_7	~0[d,e]	15[d]

[a] % *syn* + % *anti* 100. [b] From Table V. [c] Value corrected on the contribution of ylide mechanism. [d] From ref.[1]. [e] Determined in n-C_4H_9OK/n-C_4H_9OH system. [f] Determined in t-$C_5H_{11}OK$/t-$C_5H_{11}OH$ system.

DISCUSSION

Effect of Phenyl Substituents on syn-anti *Competition*

A compelling evidence has been provided by Smith[11,12] that introduction of phenyl substituent into α- or β-position of alkyltrimethylammonium ions induces shift to the reactant-like side of the variable transition state scale for β-elimination. According to the hypothesis set forth by Bailey and Saunders[1], such a shift should increase tendency for *syn*-elimination from the ammonium compounds.

Aiming to establish the effect of phenyl substituent on the *syn-anti* competition, we determined proportion of *syn*-elimination in *trans*-1-phenyl-1-propene (*trans-III*) formation from the reactions of the positionally isomeric trimethylammonium ions *I* and *II* with CH_3OK/CH_3OH and with t-C_4H_9OK/t-C_4H_9OH systems and compared the results with those previously reported[1] for *trans*-2-hexene (*trans-VI*) formation from the corresponding reactions of the α- and β-n-propyl substituted analogues *IV* and *V*. As inspection of the data in Table VII immediately reveals, the replacement of n-propyl by phenyl group does not lead to an increase but, rather, to an decrease of the *syn*-contribution, in apparent discord with the above theory.

Examination of literature provides two related pieces of experimental evidence concerning elimination from phenyl substituted 'onium compounds. According to Bourns and Frosst[27] the elimination of *threo*-(1,2-$^2H_2$)-2-phenylethyltrimethylammonium ion with t-C_4H_9OK/t-C_4H_9OH is a clean *anti*-elimination. Similarly, the elimination of *erythro*- and *threo*-1,2-diphenyl-1-propyltrimethylammonium ions[28] with CH_3OK/CH_3OH has been shown to proceed uniformly in the *anti*-fashion.* These findings contrast with the small but significant contributions of *syn*-elimination which we more recently observed in the reactions of the corresponding n-octyl[29] or n-butyl[6] substituted analogues with the same base–solvent systems (Table VIII).

In this way, the combined evidence from Tables VII and VIII casts some doubts on the significance of electronic effects in the *syn-anti* competition. If operative at all, the electronic effect of phenyl group is probably submerged by a more important steric effect in the stereochemical control.

Effect of Phenyl Substituents on trans/cis *Ratios*

The geometrical orientation in the *anti*-elimination component from the n-propyl (*IV* and *V*) and from the phenyl substituted (*I* and *II*) quaternary salts is compared

* The opposite stereochemistry (*syn*) observed in the reaction of the *erythro*-1,2-diphenyl-1-propyl derivative with t-C_4H_9OK/t-C_4H_9OH (Table VIII) was plausibly accounted by operation of a two-step (carbanionic) mechanism induced by a cooperation of "strong base and the relatively acidic hydrogens on C_β"; ref.[28]. A comparison with the corresponding reaction of the n-propyl substituted analogue would be therefore unwarranted.

in Table IX. In accord with the usual[30] behaviour of alkyltrimethylammonium salts, *trans*/*cis* ratios in the *anti*-elimination from the n-propyl substituted compounds is always lower than unity. On comparison with these "normal" values, the *trans*/*cis* ratios in the *anti*-elimination from the phenyl substituted compounds appear anomalously high.

In considering the different results, we have to take into account thermodynamic stability of the resulting olefinic pairs. For 2-hexenes, the equilibrium *trans*/*cis* ratio is about 3 (ref.[31]), whereas for 1-phenyl-1-propenes the equilibrium *trans*/*cis* ratio is reported[25] to be 18. Thus, in the elimination from the n-propyl substituted compounds *IV* and *V* the observed *trans*/*cis* ratios are far below the equilibrium value whereas in the elimination from the phenyl substituted compounds *I* and *II* the observed and the equilibrium values do not differ much.

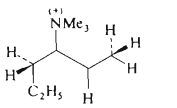
TABLE VIII

Related Evidence Concerning the Substituent Effect on *syn-anti* Competition: Literature Data

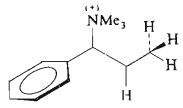
Substrate[a]	Product	% *syn*-Elimination	
		MeOK/MeOH	t-BuOK/t-BuOH
PhCD—CHD H (+)NMe$_3$ (*threo*)	PhCD=CHD	0[b]	0[b]
n-OctCD—CHD H (+)NMe$_3$ (*threo*)	n-OctCD=CHD	—	7[a]
PhC(CH$_3$)—CHPh H (+)NMe$_3$ (*threo*)	PhC(CH$_3$)=CHPh	0[d]	0[d]
n-BuC(CH$_3$)—CH-n-Bu H (+)NMe$_3$ (*threo*)	n-BuC(CH$_3$)=CH-n-Bu	0.4[e]	4.4[e]
PhC(CH$_3$)—CHPh H (+)NMe$_3$ (*erythro*)	PhC(CH$_3$)=CHPh	0[d]	100[d]
n-BuC(CH$_3$)—CH-n-Bu H (+)NMe$_3$ (*erythro*)	n-BuC(CH$_3$)=CH-n-Bu	5[e]	40[e]

[a] Me = methyl; Ph = phenyl; n-Oct = n-octyl; n-Bu = n-butyl. [b] From ref.[27]. [c] From ref.[29]. [d] From ref.[28]. [e] From ref.[6].

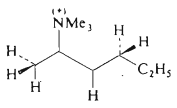
Rationalisation of the very low *trans*/*cis* ratios from the n-propyl substituted compounds *IV* and *V* has been provided in terms of base-approach hindrance in the *anti*-elimination. According to the model proposed by Saunders[1], the bulky leaving group forces the alkyl residues on C_α as well as on C_β in the 'onium substrate *IV* and *V* away from itself into conformations where approach of the base to the β-hydrogen in the *trans*-olefin formation is selectively hindered (Scheme 2). However,



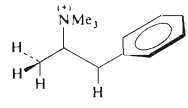
IV → *VI*



I → *III*



V → *VI*



I' → *III*

SCHEME 2

TABLE IX

Substituent Effect on Geometrical Orientation in *anti*-Elimination: A Comparison of Phenyl *vs* n-Propyl Group

$R^\alpha.CH(^{(+)}NMe_3)-CH(H).R^\beta$		$R^\alpha.CH{=}CH.R^\beta$	
		trans/*cis* Ratio in *anti*-E2	
R^α	R^β	CH_3OK/CH_3OH	$t\text{-}C_4H_9OK/t\text{-}C_4H_9OH$
C_6H_5	CH_3	15[a]	7[a]
$n\text{-}C_3H_7$	CH_3	0·3[b,c]	0·3[b,c]
CH_3	C_6H_5	23[a,c]	15[a,c]
CH_3	$n\text{-}C_3H_7$	0·3[b,c]	0·4[b,c]

[a] Calculated from data in Tables III and V. [b] Calculated from the corresponding data in ref.[1]. [c] Calculated under simplifying assumption that the contribution of *syn*-elimination in *cis*-olefin formation is negligibly small.

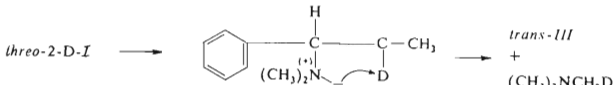
in the phenyl substituted compounds *I* and *II*, the phenyl group is rigid and cannot bend downwards (Scheme 2) to alleviate the interactions with the trimethylammonium group. Accordingly, the selective base-approach hindrance in the formation of *trans*--*III* alkene does not arise and the "anomalous" preference for *trans*- over *cis*-olefin formation is observed.

The absence of the base-approach hindrance may also explain why the *syn*-contributions in the elimination from the phenyl substituted compounds are so low. Our recent analysis of steric effects in *syn-anti* dichotomous elimination reactions[4,5] lend a full support to the original suggestion[1] that a correlation exists between the base-approach hindrance in *anti*-elimination and the propensity for *syn*-elimination.

Effect of Phenyl Substituents on the Ylide Pathways

Ylides have been occasionally observed[14,32–37] in alkoxide or hydroxide-promoted decomposition of alkyl and cycloalkyltrimethylammonium salts; however, a closer examination in most instances showed that the ylide formation represents only a blind alley in the reaction.

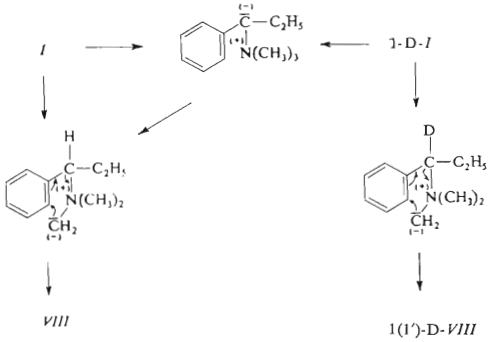
In contrast, the ylides arising from the phenyl substituted salt *I* play apparently a more prominent role. The d_1 contents determined (Table VI) in the trimethylamine set free from the reaction of the *threo*-2-D labelled analogue with t-C_4H_9OK/ /t-C_4H_9OH and, particularly, with t-C_4H_9OK/C_6H_6 systems suggest a significant participation of ylide in the olefin-*III* formation (Scheme 3). At the same time, the



SCHEME 3

simultaneous formation of the amine *VIII* (Table III), an obvious product of the Sommelet-Hauser rearrangement[38,39] (Scheme 4), demonstrates a pronounced intervention of another ylide pathway in the reaction.

For the Sommelet–Hauser rearrangement of benzyltrimethylammonium ions it has been argued[40–42] that because of the increased acidity of the hydrogen on C_α the benzyl ylide is formed first yielding then the methyl ylide which undergoes the rearrangement reaction (*cf.* Scheme 4). However, the fate of the deuterium label we traced back in the reaction of the derivative 1-D-*I* disagrees considerably with this



SCHEME 4

mechanistic scheme. In particular, determination of the d_1 species in the amine *VIII* from the reaction of 1-D-*I* with t-C_4H_9OK/C_6H_6 showed (Table II) that only 10% of the label on the benzyl carbon was lost indicating that the benzyl ylide is not substantially involved in the rearrangement reaction.

We are indebted to Dr L. Dolejš and his staff for the mass spectroscopic determinations.

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Translated by the author (J. Z.).