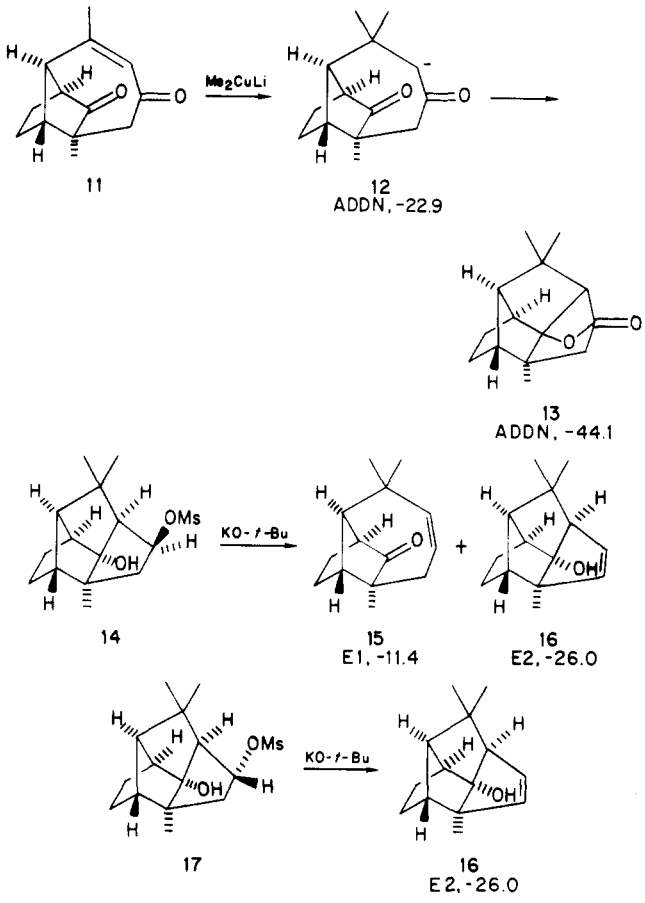
Scheme II



2). In addition to an O-alkylation (7), the program predicts both possible C-alkylation reactions (2, 3) to be viable. Although the six-membered ring product, 3, may be more thermodynamically favored, the reported product, 2 (93%),[38] contains the five-membered ring. Three E2 products (4, 5, 6) from anti eliminations and a less favorable E1 fragmentation product (8) are also output. Epoxy ketone 9, an epimer of compound 1, is predicted to give only elimination products under the same reaction conditions. The substitution reactions were considered, but were rejected because of the trans fusion which prevents the folded conformation necessary for the reaction to proceed. An additional product, 10, is predicted for this molecule as the fusion hydrogen and the epoxy leaving group are now anti. In Scheme II, the cis geometry of the nucleophilic site and carbonyl following dimethyl cuprate addition to compound 11 leads to an intramolecular addition product, 13. This product was reported in 96% yield;[38] it is the only product predicted by the program as is the 1,4-addition of dimethyl cuprate to 11.[2] Once functionalized to the hydroxymesylate 14, a Grob fragmentation occurs in the presence of base to yield product 15 (100%).[38] The program also predicts an elimination product, 16, but does not produce the intramolecular S_N2 product which, although stereochemically viable, does not compete with the facile fragmentation process. In contrast, epimer 17 is predicted to give only the E2 elimination product since neither the S_N2 nor the fragmentation has the proper stereochemical orientation.

Conclusion

The addition of stereochemical analysis to the computer synthesis program CAMEO has enhanced the sophistication of its predictions. Cis/trans and syn/anti relationships are recognized and used to ascertain stereochemical and/or physical restrictions on an organic reaction. Inversion of configuration is also addressed. Although illustrated with examples from base-catalyzed and nucleophilic chemistry, similar analyses have been incorporated throughout the mechanistic phases of the program.

Acknowledgment. Gratitude is expressed to the National Science Foundation for support of this work. The assistance of J. S. Burnier, D. R. McLaughlin, J. Gao, and B. L. Roos-Kozel is also appreciated.

Nucleophilic Attacks on Carbon-Carbon Double Bonds. 31.[1] Complete and Partial Stereoconversion in Vinylic Substitution of (*E*)- and (*Z*)-β-Chloro-α-phenylcinnamaldehydes and (*E*)-2-Iodo-1,2-diphenyl-1-nitroethylene by Nucleophiles

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Substitution of the chlorine of (*E*)- and (*Z*)-α-chloro-β-phenylcinnamaldehydes ((*E*)- and (*Z*)-**5**) by *p*-toluenethiolate (ArS^-), *p*-cresolate (ArO^-), and MeO^- ions proceeds with complete or partial stereoconversion. With ArS^- both (*E*)- and (*Z*)-**5** gave only the *E* product, whereas ArO^- and MeO^- gave different mixtures of *E* and *Z* products, where the *E* isomer predominates. With Cl^- no (*E*)-**5** ⇌ (*Z*)-**5** isomerization took place. Azide ion gave 2,4-diphenyloxazole (**10**) and 1-phenyl-5-benzyltetrazole (**11**). Reaction of (*E*)-2-iodo-1,2-diphenyl-1-nitroethylene with methoxide ion gave both *E* and *Z* substitution products and 1,2-dimethoxy-1,2-diphenylethylene. The stereochemistry of the substitution was discussed in terms of a multistep route via a carbanionic intermediate in relation to the nature of the activating group and the nucleophile. Comparison with literature cases shows that the present work extends the range of operation of the multistep substitution, as probed by stereochemistry, to systems less activated than those previously studied. The formation of the heterocycles **10** and **11** is ascribed to an initial formation of a vinyl azide followed by nitrogen loss and migration of phenyl to the nitrene formed. Cyclization with rearrangement gives **10** and reaction with another N_3^-, decarbonylation, and cyclization gives **11**. The crystal structures of (*E*)-PhC(Nu)=C(Ph)CHO, Nu = MeO, ArS, and of **10** and **11** were determined.

The stereochemistry of nucleophilic vinylic substitution via addition-elimination (eq 1, Y,Y′ = electron withdrawing groups, X = leaving group, Nu^- = nucleophile) is a strong tool in delineating the details of the mechanism of

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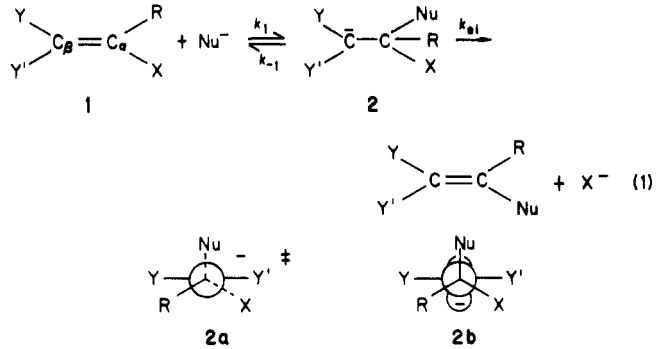
the substitution.[2] Assuming a nucleophilic attack from a plane perpendicular to the double bond plane, a concerted substitution is expected to proceed with retention of configuration, and **2** is then a transition state (cf. **2a**). However, if the reaction is a multistep process, with **2** being a carbanionic intermediate, i.e., **2b**, the stereochemical outcome depends on the lifetime and the barrier to internal rotation in **2b**.[2,3] If internal rotation in **2b** in slower than nucleofuge expulsion, retention of configuration will be observed starting either from an *E* or a *Z* precursor. However, if the rate constant for internal rotation is faster or of a comparable magnitude than k_{el}, partial or complete stereoconversion will be obtained. Complete stereoconversion means formation of identical products mixture from *E* or *Z* precursors.



We recently suggested that the transition state for nucleophilic vinylic substitution is varied[2c] and that the reaction can either be a single-step or a multistep process depending on the nature of X, Y, and Y'.[2c] The multistep process is likely to occur when the nucleofuge is a poor leaving group or when Y and Y' are highly effective in delocalizing the negative charge formed in the nucleophilic attack. More interesting cases are those where the nucleofuge is a good leaving group, e.g., Cl, Br, I, i.e., when k_{el} is very high. In most of the recorded cases with good nucleofuges the stereochemistry is retention of configuration.[2,3] However, in recent works we showed[4,5] that by using a combination of strong electron-withdrawing Y and Y' stereoconversion was indeed observed with good nucleofuges. The systems investigated were (*E*)-**3** and (*Z*)-**3**, where Y, Y' = NO_2, Ph and complete stereoconversion was observed with several nucleophiles,[4] and (*E*)-**4** and (*Z*)-**4**, (Y, Y' = CN, CO_2Me), where the stereochemical outcome was partial stereoconversion.[5,6]

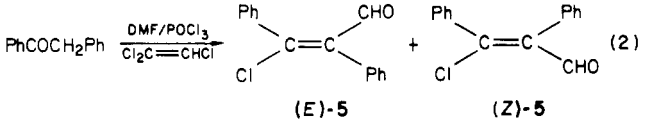
$$\underset{\mathbf{3}}{PhC(I)=C(Ph)NO_2} \qquad \underset{\mathbf{4}}{p\text{-}O_2NC_6H_4C(Cl)=C(CN)CO_2Me}$$

A main mechanistic question is what is the degree of activation, determined by Y and Y', at which a shift will occur from the multistep to the single step route. The stereochemistry can give only an upper barrier for this activation. As far as partial stereoconversion is observed and the mechanism is that depicted in eq 1, the reaction should be multistep. If retention is observed it can be either a multistep or a single-step process.[2,3]

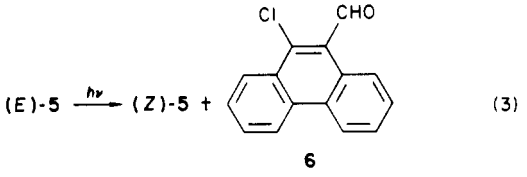
As part of a program to investigate this question we study now a system with lower activation than **3** and **4**, i.e., the (*E*)- and (*Z*)-β-chloro-α-phenylcinnamaldehydes (*E*)-**5** and (*Z*)-**5**, were Y,Y' = CHO, Ph. The system resembles **3** in its stilbene skeleton, but CHO is less capable of stabilizing a negative charge than nitro, as judged by their σ^- constants.[7] The $\sum \sigma^-$ of CN and CO_2Me is larger than σ^- of CHO[7] and a tentative intuitive prediction, which is based on additivity effects and on the assumption that the charge in **2** is delocalized mainly by Y and Y', is that system **5** will show either a partial stereoconversion or retention. Indeed, *E*/*Z* product mixtures were reported to result from the substitution of (*Z*)-RC(Cl)=C(Me)CHO (R = Me, Ph) by CNS^-,[8] although it was shown later that this may be due to an initial retention followed by postisomerization.[9]

In a previous work we found that the extent of retention in the substitution of **4** is lower for the $p\text{-}MeC_6H_4O^-$ than for the $p\text{-}MeC_6H_4S^-$ nucleophile.[5,6] Since the latter nucleophile gives complete stereoconversion with **3**, it was of interest to study the extent of stereoconversion in the reaction of **3** with an oxygen nucleophile. The reaction of (*E*)-**3** with MeO^- was therefore studied.

Preparation and Reactions of (*E*)- and (*Z*)-β-Chloro-α-phenylcinnamaldehydes ((*E*)-5 and (*Z*)-5). (a) Synthesis and Assignment. A Vilsmeier reaction of desoxybenzoin for 30 h gave a 60:40 mixture of (*E*)-**5** to (*Z*)-**5** (eq 2). The percentage of (*Z*)-**5** at shorter reaction times was lower, as also reported in the literature.[10a] (*E*)-**5** was purified by crystallization, whereas (*Z*)-**5** was obtained both from this reaction and from photochemical isomerization of (*E*)-**5**.



Irradiation of (*E*)-**5** gave mixtures which contained up to 40% (*Z*)-**5** together with ≤12% of a cyclization product, 9-chloro-10-phenanthrenecarboxaldehyde **6** (eq 3).



The stereochemistry of (*E*)-**5** and (*Z*)-**5** was assigned according to Weissenfels on the basis of the UV and the NMR spectra.[10b] The isomer with λ_{max} 283 nm (ε 9000), δ (CHO) 9.58 was assigned as (*E*)-**5** whereas the isomer with λ_{max} 298 nm (ε 7300), δ (CHO) 10.46 was assigned as (*Z*)-**5**. However, we believe that the UV data for these α,β-disubstituted stilbenes are not very useful in configuration assignment. On the basis of λ_{max} values the as-

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(2) (a) Rappoport, Z. *Adv. Phys. Org. Chem.* **1969**, *7*, 1. (b) Patai, S.; Rappoport, Z. In "The Chemistry of Alkenes"; Patai, S., Ed.; Interscience: London, 1964; Chapter 8. (c) Rappoport, Z. *Acc. Chem. Res.* **1981**, *14*, 7. (d) Modena, G. *Acc. Chem. Res.* **1971**, *4*, 73. (e) Miller, S. I. *Tetrahedron* **1977**, *33*, 1211.

(3) Apeloig, Y.; Rappoport, Z. *J. Am. Chem. Soc.* **1979**, *101*, 5095.

(4) Rappoport, Z.; Topol, A. *J. Am. Chem. Soc.* **1980**, *102*, 406.

(5) Rappoport, Z.; Avramovitch, B. *J. Org. Chem.* **1982**, *47*, 1397.

(6) We previously reported that the substitution of either (*E*)-**4** or (*Z*)-**4** with $p\text{-}MeC_6H_4S^-$ gave exclusively the *Z* substitution product, i.e., the stereochemistry is *complete* stereoconversion. A reexamination has showed that different *E*/*Z* product mixtures are formed from (*E*)-**4** and (*Z*)-**4**, i.e., the stereochemistry is a *partial* stereoconversion (Avramovitch, B., unpublished results).

(7) the σ^- values of NO_2, CHO, CN, and CO_2Et are 1.27 , 1.13, 1.00, and 0.68, respectively (Jaffe, H. H. *Chem. Revs.* **1953**, *53*, 191).

(8) Korobov, M. S.; Nivorozhkin, L. E.; Minkin, V. I. *Zh. Org. Khim.* **1973**, *9*, 1717; *J. Org. Chem. USSR Engl. Transl.* **1973**, 1739.

(9) Korobov, M. S.; Nivorozhkin, L. E.; Minkin, V. I.; Levkovich, M. M.; Testoedova, S. I. *Zh. Org. Khim.* **1978**, *14*, 788; *J. Org. Chem. USSR Engl. Transl.* **1978**, 728.

(10) (a) Weissenfels, M.; Schurig, H.; Hühsam, G. *Z. Chem.* **1966**, *6*, 471. (b) Weissenfels, M.; Pulst, M.; Schneider, P. *Ibid.* **1973**, *13*, 175.

Table I. Spectral Data for the PhC(X)=C(CHO)Ph System

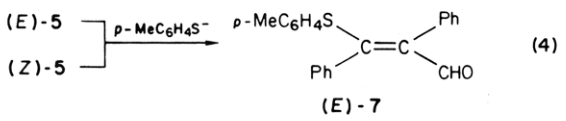
X	compd	λ_{max} (EtOH) (ϵ)	ν_{max}(C=O), CCl_4, cm^{-1}	δ ($CDCl_3$) Me or OMe	Ar	CHO
Cl	(*E*)-**5**	225 (16 300), 254 sh (11 200), 263 sh (10 800), 283 (10 900)[a]	1680		7.30–7.60	9.68 (9.56)[b]
	(*Z*)-**5**	227 (15 000), 290 (11 200)[c]	1680		6.96–7.26	10.60
STol	(*E*)-**7**	226 sh (15 200), 240 sh (10 700), 260 (8900), 314 (12 200)	1650	2.18	6.90 (AB q) 7.17–7.50 (m)	9.39 (9.39)[b]
	(*Z*)-**7**	242 sh (14 600), 264 sh (10 300), 304 (6600)	1655[d]	2.36	7.0–7.50	9.47 (9.66)[b]
OMe	(*E*)-**9**	232 (9100), 240 (9300), 283 (11 600)	1665	3.49	7.26–7.55	9.36
	(*Z*)-**9**			3.64	6.90–7.30	10.48
OTol	(*E*)-**8**	225 (29 500), 291 (14 000)	1670	2.16	6.84 (AB q) 7.26–7.51	9.73
	(*Z*)-**8**	226 (21 100), 249 sh (9300), 298 (7900)	1675	2.20	6.95 (AB q) 7.1–7.40	10.43

[a] Lit.[10b] 283 nm (ϵ 9040). [b] In C_6D_6. [c] Lit.[10b] nm (ϵ 7300). [d] In $CHCl_3$.

signments should be reversed (λ_{max} 295.5 nm and 280 nm for *trans*- and *cis*-stilbene, respectively),[10b] whereas the differences in the ϵ's, which are much smaller according to our measurements (Table I) are too small for an unequivocal conclusion. The NMR's seem to be a better guide for the assignment, although with these tetrasubstituted ethylenes they are based on analogies. In β-phenyl-substituted vinyl aldehydes, a CHO group trans to a phenyl moiety is always at a lower field compared with a CHO cis to phenyl.[10b,11] Also, the aromatic protons of *trans*-stilbenes are usually at a lower field compared with those of *cis*-stilbenes, in line with the assignment, but this could be modified by the α- and β-substituents.[12]

Since the stereochemical argument is based on correct structural assignment of the precursor and products we sought an unequivocal assignment by X-ray diffraction of (*E*)-**5**. Although the complete structural details could not be obtained,[13] it was shown unequivocally that the two phenyl groups are trans to one another. Consequently, we have no doubt that the structural assignments of the precursor and the products (see below, Table II) are correct.

(b) Reaction with Nucleophiles. (i) With *p*-Toluenethiolate Ion. Reaction of either pure (*E*)-**5** or pure (*Z*)-**5** with *p*-toluenethiolate ion in DMF gave exclusively the *E* substitution product (*E*)-α-phenyl-β-(*p*-tolylthio)cinnamaldehyde (*E*)-**7** (eq 4). Initial assignment was based on the position of the CHO signal, which like in all the other *E* isomers is <10 ppm, but since the other isomer was not obtained (however, see below) an unequivocal assignment was obtained by X-ray crystallography. The numbering scheme and important bond lengths and angles are given in Table II. A stereoscopic view is given in the supplementary Figure S1 and additional crystallographic data are given in the supplementary Tables S1–S4.



(*E*)-**7** (4)

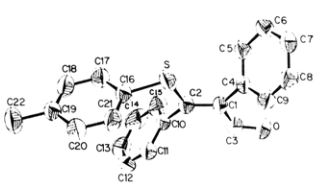
The reactions are relatively slow, so that the nucleophile is present in the solution for a relatively long time. In order to reduce the extent of possible nucleophile-catalyzed (*E*)-**7** $\rightleftharpoons$ (*Z*)-**7** isomerization, the nucleophile was added portionwise over 47 h, in such a way that the nucleophile concentration was always lower than that of (*E*)-**5**. Analysis of samples during the reaction also showed only the presence of (*E*)-**7** and unreacted (*E*)-**5**.

The isomeric halide (i.e., (*Z*)-**5** in the reaction of (*E*)-**5** and vice versa) was not observed in any of these reactions.

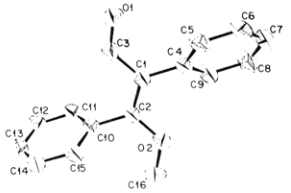
In one experiment a six months old *p*-toluenethiolate ion was reacted with (*E*)-**5** instead of a fresh sample. A new compound was observed which consisted ca. 50% of the product. We were unable to obtain the new compound in the pure form, and it was admixed with 15% of (*E*)-**7**, but the analysis was consistent with that of (*Z*)-**7**. However the UV data showed that the longer wavelength maxima is lower than that of (*E*)-**7** whereas δ (CHO) is <10 ppm. Although the data are given in Table I as due to (*Z*)-**7**, the assignment is questionable. The reaction was irreproducible and was not observed again.

(ii) With *p*-Cresolate Ion. Reaction of (*E*)-**5** with *p*-cresolate ion in DMF was slower than the reaction with

Table II. Important Bond Lengths and Angles for (*E*)-7 and (*E*)-9



(*E*)-**7**



(*E*)-**9**

compd	bond	length, A°	angle[b]	deg
(*E*)-**7**[a,b]	S–C(2)	1.753 (3)	C(1)–C(2)–C(10)	124.7 (3)
	S–C(16)	1.776 (2)	O–C(3)–C(1)	124.7 (4)
	O–C(3)	1.207 (3)	S–C(2)–C(1)	117.7 (2)
	C(1)–C(2)	1.368 (3)	S–C(2)–C(10)	117.4 (2)
	C(1)–C(3)	1.458 (4)	C(3)–C(1)–C(4)	119.0 (3)
	C(1)–C(4)	1.491 (3)	C(2)–C(1)–C(3)	119.2 (3)
	C(19)–C(22)	1.510 (4)	C(2)–S–C(16)	109.4 (2)
	C(2)–C(10)	1.484 (3)	C(2)–C(1)–C(4)	121.7 (3)
(*E*)-**9**[c,d]	O(1)–C(3)	1.213 (2)		
	O(2)-C(2)	1.350 (1)	O(1)–C(3)–C(1)	125.9 (1)
	O(2)–C(16)	1.429 (2)	C(1)–C(2)–C(10)	124.7 (1)
	C(1)–C(2)	1.361 (1)	O(2)–C(2)–C(1)	117.2 (1)
			O(2)–C(2)–C(10)	118.1 (1)
	C(1)–C(3)	1.455 (2)	C(3)–C(1)–C(4)	119.2 (1)
	C(1)–C(4)	1.488 (1)	C(2)–O(2)–C(16)	120.9 (1)
			C(2)–C(1)–C(3)	117.9 (1)
	C(2)–C(10)	1.497 (2)	C(2)–C(1)–C(4)	122.9 (1)

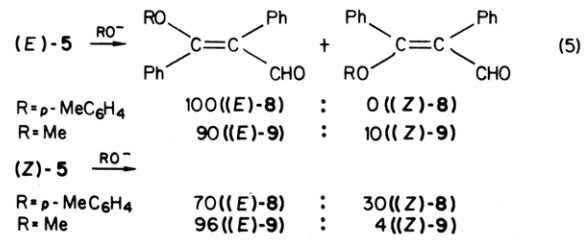
[a] All the aromatic bond lengths are between 1.360 (7) Å and 1.390 (4) Å (Table S1). [b] All the other angles are between 118.2° and 121.5° (Table S2). [c] Aromatic bond lengths are between 1.374 (2) and 1.395 (2) Å (Table S5). [d] All the other angles are between 118.1° and 120.9° (Table S6).

(11) Gazit, A.; Rappoport, Z., unpublished results on the *p*-$O_2NC_6H_4C(Cl)$=C(CHO)COOMe system.

(12) "NMR Spectra Catalog", Varian Associates, Palo Alto, CA, 1962, Spectra 305, 306. Güsten, H.; Salzwedel, M. *Tetrahedron* **1967**, *23*, 173, 187. Davis, D. R.; Roberts, J. D. *J. Am. Chem. Soc.* 1962, *84*, 2252.

(13) A large disorder in the positions of the Cl and the CHO prevented accurate determination of their positions, i.e., of the bond lengths and angles associated with them. Hence, the data for (*E*)-**5** are not given.

p-toluenethiolate ion and gave exclusively (*E*)-α-phenyl-β-(*p*-tolyloxy)cinnamaldehyde ((*E*)-**8**) with no traces of (*Z*)-**8** or (*Z*)-**5** (eq 5). In contrast, (*Z*)-**5** gave a mixture of two vinyl ethers in a ratio of 7:3 of (*E*)-**8** to (*Z*)-**8** which remained unchanged after 6 or 48 h (eq 5). The assignment is based on the UV and ^{1}H NMR spectra (Table I).

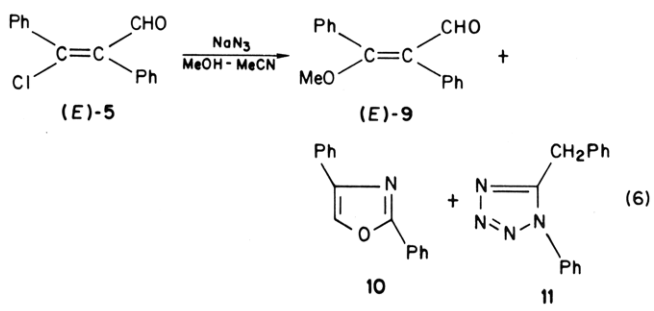


(iii) With Methoxide Ion. The reaction of (*E*)-**5** with NaOMe in MeOH was faster than the reaction with *p*-cresolate ion in DMF and gave a 9:1 mixture of (*E*)- to (*Z*)-β-methoxy-α-phenylcinnamaldehydes (*E*)-**9** and (*Z*)-**9** (eq 5). The structures were assigned by NMR of the CHO signals (Table I) and that of (*E*)-**9** was corroborated by X-ray crystallography. The spectral properties of the main product from the substitution were identical with those of the compound obtained in the reaction with N_3^- (see below) and whose structure was determined by crystallography. Since (*Z*)-**9** was obtained in a mixture with (*E*)-**9**, its UV spectrum could not be determined.

The reaction of (*Z*)-**5** gave (by NMR of the crude sample) a 96:4 (*E*)-**9**/(*Z*)-**9** mixture. Reaction of (*E*)-**9** with 1.2 molar equiv of NaOMe for 5 h gave back (*E*)-**9** with no traces of (*Z*)-**9**. Consequently, a high extent of stereoconversion was obtained.

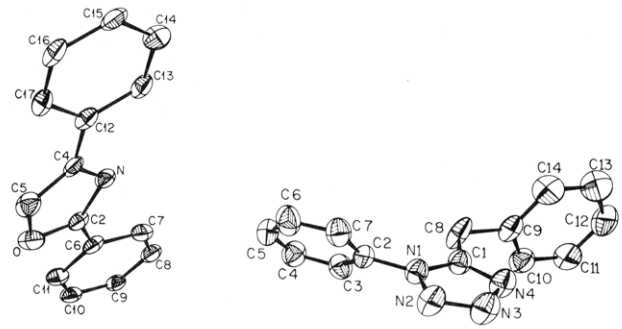
The anionic nucleophile is much more reactive than a neutral alcohol. Reflux of (*E*)-**5** with ethanol for 6 h gave only unreacted (*E*)-**5**.

(iv) With Azide Ion. The reaction of (*E*)-**5** with azide ion in MeOH–MeCN gave at least six compounds by TLC. Three of them were isolated, but since none of them was the vinylic azide and since the spectral data could not give an unequivocal evidence for their structures, the three structures were determined by X-ray crystallography. One compound is (*E*)-**9** (the numbering scheme and important bond lengths and angles are given in Table II and additional crystallographic data and a stereoscopic view are given in the supplementary Tables S5–S8 and in Figure S2). The other compounds are two heterocyclic derivatives: 2,4-diphenyloxazole (**10**) and 1-phenyl-5-benzyltetrazole (**11**) (eq 6). Numbering schemes and important bond lengths and angles are given in Tables III, and stereoscopic views and additional crystallographic data are given in the supplementary Figures S3 and S4 and Tables S9–S16.



It should be emphasized that while there is no problem with the structures of (*E*)-**9** and **11**, there were problems associated with the structure determination of **10**. While the presence of a five-membered heterocycle with phenyl groups at 1,3-positions is clear, the R factor was high.

Table III. Important Bond Lengths and Angles for 10 and 11



compd	bond	length, Å	angle	deg
10[a,b]	"O"–C(2)	1.35 (1)	C(2)–"O"–"C(5)"	103.6 (7)
	"O"–"C(5)"	1.44 (1)	"O"–"C(5)"–C(4)	105.6 (7)
	C(2)–N	1.33 (1)	"C(5)"–C(4)–N	112.9 (8)
	C(2)–C(6)	1.47 (1)	C(4)–N–C(2)	104.7 (7)
	N–C(4)	1.34 (1)	N–C(2)–"O"	113.0 (7)
	C(4)–"C(5)"	1.32 (1)	N–C(2)–C(6)	127.0 (8)
	C(4)–C(12)	1.48 (1)	N–C(4)–C(12)	125.9 (8)
11[a,d]	N(1)–N(2)	1.355 (2)	C(1)–N(1)–N(2)	108.2 (1)
	N(2)–N(3)	1.293 (2)	N(1)–N(2)–N(3)	106.2 (1)
	N(3)–(N4)	1.367 (2)	N(2)–N(3)–N(4)	110.8 (2)
	N4)–C(1)	1.310 (2)	N(3)–N(4)–C(1)	105.9 (2)
	C(1)–N(1)	1.344 (2)	N(4)–C(1)–N(1)	108.8 (2)
	N(1)–C(2)	1.440 (2)	C(1)–N(1)–C(2)	131.8 (2)
	C(1)–C(8)	1.494 (3)	C(1)–C(8)–C(9)	112.8 (2)
	C(8)–C(9)	1.513 (2)	N(1)–C(1)–C(8)	124.8 (2)
			N(4)–C(1)–C(8)	126.4 (2)

[a] All the aromatic bond lengths are 1.38 (1)–1.42 (1) Å (Table S9). [b] All the other angles are 119.1 (8)° –121.8 (8°), except for the C(8)–C(9)–C(10) angle which is 118.1 (8)° (Table S10). [c] All aromatic bond lenghts are 1.369 (3)-1.387 (3) Å (Table S13). [d] All the other angles are 118.5 (2)° –121.6 (2)° (Table S14).

Hence, the structure was redetermined at low temperature. However, the crystal structure exhibits a 2-fold disorder between the oxygen and the C-5 sites. Each site has actually the same chance to be occupied either by an O atom or a C atom. The R factors for 2,4-diphenyl- and 2,5-diphenyloxazole are 0.108 and 0.110, respectively, but by taking the disorder into account and "assuming" that O and C-5 have indeed the same chance to be at their positions, the R factor for 2,4-diphenyloxazole becomes 0.097. In Tables III and S9–S12 "O" and "C–5" are related to the structure obtained by this assumption. Chemical evidence corroborates the suggested structure. The ^{1}H NMR of 2,5-diphenyloxazole (PPO), mp 74 °C,[14] differs from that of **10** and the mixed mp is 59 °C. The published UV data and the mp (141 °C) of 3,5-diphenylisoxazole differ from those of **10**.[15] On the other hand, the literature mp of 2,4-diphenyloxazole (103 °C)[16] is the closest to that observed (96 °C) for **10**.

(v) With Chloride Ion. Reaction of a 2.2:1 ratio of Bu_4NCl to (*E*)-**5** in $CDCl_3$ for 267 h at room temperature resulted in isomerization to a 77:23 (*E*)-**5**/(*Z*)-**5** mixture. However, a control experiment in the absence of the ammonium salt gave a 76:24 and 77:23 (*E*)-**5**/(*Z*)-**5** mixture after 90 and 117 h, respectively.

This experiment suggested that a photochemical rather than a Cl^--catalyzed thermal (*E*)-**5** ⇌ (*Z*)-**5** isomerization takes place. Consequently, the two experiments were conducted in the dark. From a 1.8:1 Bu_4NCl/(*E*)-**5** mixture in $CDCl_3$ no (*Z*)-**5** was detected by ^{1}H NMR after 20,

(14) Fischer, E. *Chem. Ber.* **1896**, *29*, 207.
(15) Singh, B.; Ullman, E. F. *J. Am. Chem. Soc.* **1967**, *89*, 6911.
(16) Lewy, M. *Chem. Ber.* **1887**, *20*, 2579.

Table IV. Stereochemistry of Substitution of (*E*)-5 and (*Z*)-5[a]

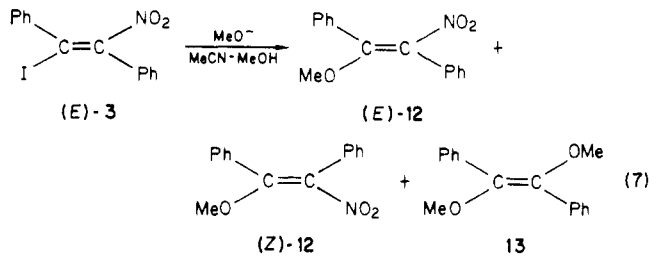
compd	nucleophile[b]	solvent	[5]/[Nu⁻]	reactn time, h	products[c]	yield,[d] %	recovered[e] 5, %
(*E*)-5	ArS^-	DMF	1.0	24	(*E*)-7	23 (43)	46
			0.8–1.3[f]	48	100% (*E*)-7		50
			1.3	22	65:35 (*E*)-7/(*Z*)-7 (?)[g]		50
(*Z*)-5			1.2	48	100% (*E*)-7	23	
(*E*)-5	ArO^-	DMF	1.1	26	100% (*E*)-8	20 (36)	45
(*Z*)-5			1.2	48	70:30 (*E*)-8/(*Z*)-8	26 (38)	30
(*E*)-5	MeO^-	MeOH	1.5	5	90:10 (*E*)-9/(*Z*)-9	56	
(*Z*)-5			1.4	5	96:4 (*E*)-9/(*Z*)-9	74	

[a] Reaction at room temperature unless otherwise stated. [b] Ar = *p*-MeC_6H_4. [c] Ratio based on the NMR of the crude reaction mixture. [d] Isolated yield. In parenthesis, yield corrected for the recovered 5. [e] Only the starting halide but not its isomer was recovered or detected. [f] Stepwise addition of the nucleophile. [g] An old solution of ArS^- was used.

70, and 110 h, whereas in the absence of Bu_4NCl a signal corresponding to ≤2% (*Z*)-5 was observed after 140 h.

Reaction of (*E*)-3 with MeOH and with MeO^- Ion. Substitution of (*E*)-3 by basic methanol is apparently very slow since only traces of a methoxy-containing product were obtained from reaction at room temperature after 24 h.

The reaction with MeO^- in a 6:100 (v/v) MeOH–MeCN mixture is also slow, but after 140 h at room temperature 56% of a mixture of the two substitution products (*E*)-12 and (*Z*)-12 together with a low yield (4%) of the disubstitution product 13 were isolated (eq 7). Attempted separation of (*Z*)-12 and (*E*)-12 by repeated chromatography and recrystallization have failed. If we ascribe the low field MeO signal as being due to a methoxy trans to a phenyl group, then the (*E*)-12/(*E*)-12 ratios before separation and after chromatography were 3:7 and 4:6, respectively.



Only one isomer of 13 was isolated and an *E* structure is tentatively suggested only on the basis of a steric argument.

Discussion

Substitution of (*E*)-5 and (*Z*)-5. Complete and Partial Stereoconversion. (a) Reliability of the Stereochemical Assignments. For discussing the stereochemistry of the substitution, two prerequisites must be fulfilled. The first and most important is to have unequivocal stereochemical assignments of the reagents and products. There are cases in nucleophilic vinylic substitution where an argument related to the stereochemistry of the reaction was based on conflicting structural assignment.[17] The second is to know whether the product distribution is due to a thermodynamic or to a kinetic control.

Concerning the first prerequisite, an unequivocal stereochemical assignment should be based on X-ray crystallography. With α,β-substituted stilbenes the UV spectra is unreliable as a stereochemical guide, since the order of λ_{max} and ε values for *E*/*Z* pairs depends on the bulk of the α- and β-substituents.[18] Likewise, although there are regularities in the positions and widths of the aromatic multiplets, a reliable assignment is impossible when only a single isomer is available. In our system, inspection of Table I shows that the δ values of the aldehyde proton of the two isomers are sufficiently separated in the two isomers, so that they can be used as a stereochemical probe. The small separation between the values for (*E*)-7 and the (presumably) (*Z*)-7 raises a doubt concerning this probe. Therefore, we felt that anchoring these differences with crystallographic data would give reliable data for the stereochemical discussion. The crystal structures of (*E*)-5,[13] (*E*)-7, and (*E*)-9, combined with the δ (CHO) values give us confidence that our stereochemical assignments are correct.

Concerning the second prerequisite we note that only (*E*)-7 is formed in the substitution even at early reaction time when the nucleophile concentrations are smaller than that of (*E*)-5, and that different *E*/*Z* mixtures were formed with the oxygen nucleophiles starting from (*E*)-5 or (*Z*)-5.

Consequently, we believe that our product distributions reflect the kinetically controlled ratios and our discussion is based on this assumption. The stereochemical data are collected in Table IV.

(b) The Substitution Mechanism. Dependence of the Stereochemistry on the Nucleophile. Of the five nucleophiles studies (*p*-$MeC_6H_4O^-$, *p*-$MeC_6H_4S^-$, MeO^-, Cl^-, N_3^-) only three give information on the stereochemistry of the reaction. With N_3^- the nitrogen-containing products are derived from an initial substitution product, which lost the stereochemistry by further rearrangements and cyclizations. The mechanism of this reaction is discussed below.

The absence of Cl^--catalyzed (*E*)-5 ⇌ (*Z*)-5 isomerization in the dark is a part of the substitution mechanism, as discussed below.

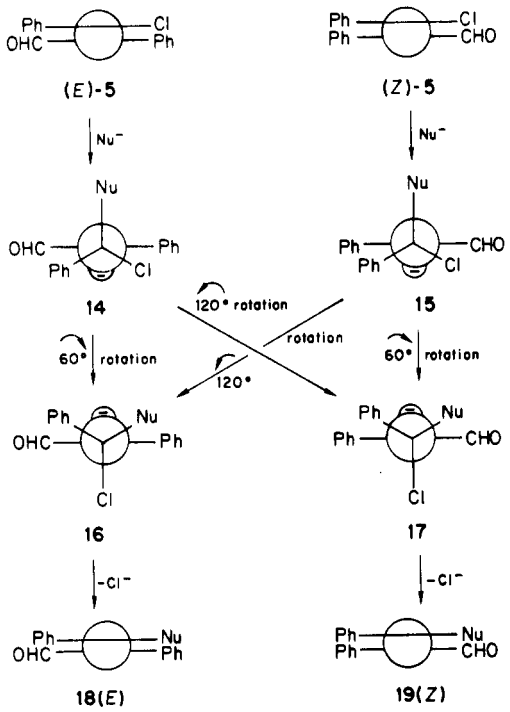
The partial or complete stereoconversion indicated by the results in Table IV suggests that the reaction proceeds via the multistep substitution route. The details of this route are given in Scheme I. A perpendicular nucleophilic attack[19] on (*E*)-5 and (*Z*)-5 gives the carbanion conformers 14 and 15, respectively. 60° clockwise rotation in the two carbanions gives their conformers 16 and 17 in which the chlorine atom is in a suitable position for expulsion. Anticlockwise 120° rotation gives 17 from 14 and 16 from 15 (neglecting differences in enantiomers). Chloride ion expulsion from 16 and 17 gives the nucleophile-containing products 18 and 19. Hence the (*E*)-5 → 14 → 16 → 18 and the (*Z*)-5 → 15 → 17 → 19 routes lead to retention, and the (*E*)-5 → 14 → 17 → 19 and (*Z*)-5 → 15 → 16 → 18

(17) (a) Rappoport, Z.; Topol, A. *J. Chem. Soc., Perkin Trans 2* **1975**, 982. (b) Le Guillanton, G.; Cariou, M. *Ibid.* **1977**, 997. (c) Rappoport, Z. *Ibid.* **1977**, 1000.

(18) Suzuki, H. "Electronic Absorption Spectra and Geometry of Organic Molecules"; Academic Press: New York, 1967.

(19) A "perpendicular nucleophilic attack" means attack from a plane perpendicular to the double bond plane. For calculation details concerning the angle of approach, see: Stozier, R. W.; Caramella, P.; Houk, K. N. *J. Am. Chem. Soc.* **1979**, *101*, 1340.

Scheme I



routes lead to inversion. Note that **16** can be formed from **14**, and **17** from **15** by a 300° anticlockwise rotation. Consequently, partial or complete stereoconversion is obtained when the lifetime of the intermediate carbanion is sufficiently long to undergo an internal rotation (**14** → **17**, **15** → **16**) which is of a comparable or a faster rate (k_{rot}) than leaving group expulsion (k_{el}).

The stereochemistry differs for the thio and for the oxygen nucleophiles. With the *p*-toluenethiolate ion only (*E*)-**7** was formed from both (*E*)-**5** and (*Z*)-**5**, i.e., the reaction gives complete stereoconversion. In contrast, with the two oxygen nucleophiles the *E*/*Z* product distributions are different, starting from (*E*)-**5** and from (*Z*)-**5** different (*E*)-**8**/(*Z*)-**8** and (*E*)-**9**/(*Z*)-**9** ratios are obtained, i.e., the reaction gives partial stereoconversion. With both oxygen nucleophiles the *E* product ((*E*)-**8**, (*E*)-**9**) predominates, but the product spread is smaller with MeO^- as the nucleophile.

If we relate to the *E*/*Z* distribution as kinetically controlled, the product distribution can be discussed in terms of Scheme I. For $Nu^- = ArS^-$ $k_{rot} > k_{el}$ and the stereochemistry is solely determined by the relative energies of the two transition states for elimination. Since (*E*)-**7** is the only product, it is the thermodynamically more stable isomer and the transition state for the **14** → **16** → **18** route is at least 2.5 kcal mol^{-1} more stable than that for the **14** → **17** → **18** route. Since the main differences are in the steric interactions between eclipsing groups the sum of the steric interactions for the pairs ArS, Ph and Ph, CHO is lower than for the pairs Ph, Ph and ArS, CHO. Due to the linearity of the CHO group and to the fact that the bulk of the ArS group is removed from the reaction center by the (itself bulky) S atom it seems that the major interaction dictating the stereochemistry is the Ph, Ph interaction. We note that if more charge is delocalized in the elimination transition state into the β-CHO compared with the β-Ph group, a stabilizing electrostatic attractive interaction between the partially positively charged sulfur and the partially negatively charged oxygen in the transition state will favor **17** over **16**, i.e., the *Z* over the *E* isomers. A similar interaction was previously invoked to account for the preference of the *Z* substitution product in the reaction of **4** with $p\text{-}MeC_6H_4S^-$.[5] Apparently, this interaction is insufficient to overcome the repulsive steric interaction.

With the oxygen nucleophiles the situation is different. The different product ratios cannot be completely thermodynamically controlled and should be properly analyzed in terms of sum of retention and inversion routes or in terms of the k_{rot}/k_{el} ratio combined with the analysis of the relative stabilities of the elimination transition states.[20] Comparison with the case of the sulfur nucleophile indicates a shorter lifetime for the carbanionic intermediate with oxygen nucleophile compared with sulfur. Two factors should then be considered: a faster k_{el} or a slower k_{rot} for the oxygen carbanion or a combination of the two effects. Concerning k_{el}, previous analysis used literature values for the solvolysis of GCH_2Cl (G = O, S) as a crude model for the relative k_{el} values.[5] The k_o/k_s values were most large,[21] in line with our observations, but values lower than unity were also found.[21] Concerning k_{rot}, MO calculations of the hyperconjugation barrier to internal rotations in $GCH_2CH_2^-$ carbanions in the gas phase gave a 2.3 kcal mol^{-1} lower barrier for G = SH than for G = OH.[3] Although a rationalization for the higher stereoconversion with sulfur is thus obtained, we feel that data on further systems are necessary for formulating valid generalizations.

The smaller product spread with MeO^- compared with ArO^- is consistent with the smaller steric effects in the elimination transition state for MeO^-. However, we expect k_{rot} to be lower for MeO^- since the rotational barrier will be higher if the charge on the oxygen is less delocalized. Since the solvent is protic (MeOH) in the MeO^- reaction and aprotic in the ArO^- reaction (DMF), solvation can serve as an efficient way to delocalize the charge, overcoming the higher barrier expected for an isolated molecule.

The main qualitative conclusion is that a system activated by both CHO and Ph groups still gives intermediates with sufficiently long lifetimes to manifest their presence by stereoconversion. The range of systems for which the experimental evidence shows the operation of the multistep route is thus extended.

Comparison with systems **4** and **3** (see below) should enable verification of the simplified prediction that higher electron withdrawal from C_β should be reflected in higher extents of stereoconversion. There is a similarity in the fact that the sulfur nucleophile gives more stereoconversion but an important difference is that with Cl^- as a nucleophile no Cl^--catalyzed (*E*)-**5** ⇌ (*Z*)-**5** isomerization was observed, whereas an analogous process was observed for system **4**. The prediction is that system **5** will give less stereoconversion than the more activated systems **3** and **4**. The lack of isomerization with Cl^- is consistent with this prediction since isomerization when the nucleophile is identical with the nucleofuge proceeds via Scheme I with $Nu^- = Cl^-$. Unfortunately, although the isomerization probe is better than the substitution probes with the other nucleophiles since it is free from considerations of the product stabilities, the absence of isomerization is not unequivocal. Halide ions are much less nucleophilic in nucleophilic vinylic reactions than the ArG (G = S, O)

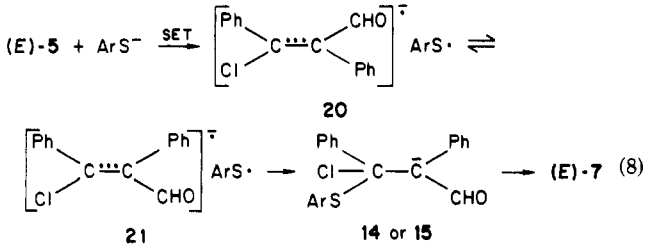
(20) In the rotational process two eclipsing interactions do not simultaneously occur. Hence, the larger interaction will mainly determine the rotational barrier. Since noneclipsing interactions also contribute to the barrier and since in the elimination process two partially eclipsing interactions occur simultaneously all these steric interactions should be considered when $k_{rot} \sim k_{el}$.

(21) Modena, G.; Scorrano, G.; Venturello, P. *J. Chem. Soc., Perkin Trans 2* **1979**, 1. Chwang, W. K.; Kresge, A. J.; Wiseman, J. R. *J. Am. Chem. Soc.* **1980**, *101*, 6972. Taft, R. W., Jr.; Martin, R. H.; Lampe, F. W. *Ibid.* **1965**, *87*, 2490. Saeva, F.; Olin, G. R. *Ibid.* **1980**, *102*, 299.

nucleophiles[2a] and the absence of isomerization may be due to a slower nucleophilic attack. Moreover, the solvent is different in the two cases. A reliable comparison requires comparison between the isomerization rates of the various systems under identical conditions, and such conditions were not found yet.

Qualitatively, the extent of stereoconversion with ArS^- is higher with system **5** than with system **4**,[13] while with the oxygen nucleophiles the opposite is true. The simplified prediction is expected to fail when the nucleophilic moiety in the carbanionic intermediate also affects k_{rot} and k_{el} of the two systems compared to a different extent. This is apparently the case where $k_{rot} > k_{el}$, i.e., when steric effects on the elimination transition states predominate. The different steric bulk of the α- and β-substituents in both systems should affect the extent of stereoconversion, and this will be superimposed on the delocalizing effect of the β-substituents. Again, a quantitative analysis is premature in the present case.

Possibility of Stereoconversion via Competing Routes. That the stereoconversion could be obtained via alternative routes to Scheme I should always be considered. An example is the photochemical (*E*)-**5** ⇌ (*Z*)-**5** isomerization in the presence of Cl^-. Of the other possible routes, preisomerization of (*E*)-**5** or (*Z*)-**5** is excluded due to their stability and postisomerization via rotation around the C=C double bond in the products is unlikely in view of its absence in more polarized ethylenes.[5] Two routes to be considered are nucleophile-catalyzed product isomerization, via nucleophilic addition–elimination forming $PhC(Nu)_2CH(Ph)CHO$ and initial electron transfer. The former route should lead to change in the product distribution during the reaction and is excluded since it was not observed with ArS^- as the nucleophile. The latter route (SET, eq 7) was not investigated in the present case, except that no (*E*)-**5** ⇌ (*Z*)-**5** isomerization during the reaction was observed. Precursor isomerization is expected by this route if the electron transfer is reversible (i.e., (*E*)-**5** → **20** → **21** → (*Z*)-**5** and rotation in the radical anion is faster (**20** → **21**) than radical recombination. Since eq 8 is also multistep involving **14** or **15** as an intermediate, our conclusion will remain unchanged even if eq 8, rather than eq 1, is the detailed substitution route.



(8)

Stereoconversion in the Reaction of MeO^- with (*E*)-3. The lower extent of stereoconversion for oxygen compared with thio nucleophiles for systems **4** and **5** suggested that a similar behavior may be found for the more activated system **3**. We reported that with CNS^- and $p\text{-}MeC_6H_4S^-$ a complete stereoconversion with formation of only one product was observed.[4] This was corroborated again now. The new study with MeO^- as the nucleophile showed three different features. First, in methanol and in a MeCN–MeOH mixture the reaction was very slow, much slower than the reaction with the thio nucleophile. The slowness of the reaction is still surprising to us. Second, both (*E*)-**12** and (*Z*)-**12** were formed and this is the first time that both *E* and *Z* products were formed with this system. The failure in separating them may be due to their rapid interconversion by internal rotation around the C=C bond. Since the reaction with (*Z*)-**3** gave several products it was not investigated further, but from the results with (*E*)-**3** it can be concluded that stereoconversion also takes place with MeO^-. Since the extent of the stereoconversion is unknown, it is impossible to decide whether it is lower than with the thio nucleophiles, in spite of the formation of *E*/*Z* product mixture. Finally, disubstitution, involving both the iodine and the β-nitro groups as nucleofuges, took place. There are precedents to similar processes in both vinylic[22] and nucleophilic heteroaromatic[23] substitution of nitro activated systems, but we note that if the substitution of the iodine takes place first, as is most likely, the second step, i.e., substitution of (*E*)- or (*Z*)-**12** should be very slow since the system is relatively unactivated.

Side Reactions. We ascribe the formation of (*E*)-**9**, **10**, and **11** in the reaction with N_3^- to initial nucleophilic substitution followed by consecutive reactions. The N_3^-/MeOH–MeCN medium is apparently sufficiently basic to form a small concentration of MeO^- which competes effectively with the N_3^- in attack on (*E*)-**5**. Substitution according to Scheme I gives mainly (*E*)-**9** and a small percentage of (*Z*)-**9** is probably present in the fraction of minor components which was not investigated further.

Formation of the oxazole **10** and the tetrazole **11** is initiated by nucleophilic attack of the azide on C_α, forming the vinyl azide **22** (Scheme II). As with other vinyl azides which are substituted by α-electron-withdrawing groups, nitrogen loss at room temperature leads to the nitrene **23**.[24] The nitrene undergoes two competitive reactions. (a) Cyclization to 2,3-diphenyl-3-azirinecarboxaldehyde **24** is followed by intramolecular attack of the oxygen with ring opening of the strained three-membered ring to form the oxazole **10**. Cyclization to azirine and formation of oxazoles (and isoxazoles) from azirines are known reactions.[25] (b) Migration of the phenyl to the nitrogen of **23** gives the ketenimine **25**. Although a recent review does not report the formation of tetrazoles from ketenimines,[26] nucleophilic attack of N_3^- on a substituted imidoyl chloride gives the azide, which then cyclizes to the tetrazole.[27] Consequently, nucleophilic attack of N_3^- on the central carbon of **25** results in the formation of the carbanion **26** which then protonates to **27**. Cyclization of the azido–azomethine moiety to the tetrazole **28** is followed by CO loss or initial loss of CO (to **29**) is followed by cyclization. All the steps, except the easy decarbonylation at room temperature have precedents, e.g., in the formation of *N*-aryl-substituted ketenimine from the reaction of $p\text{-}O_2NC_6H_4C(Cl)=C(CN)CO_2Me$ with N_3^-,[5] or in the formation of 1,5-diphenyltetrazole from $Ph_2C(N_3)_2$.[28] The loss of CO is, to our knowledge, unusual since the activating group usually remains attached to the tetrazole, as in the formation of

(22) For nitro as a leaving group in the nucleophilic substitution of 9-(nitromethylene)fluorene see: Hoz, S.; Speizman, D. *J. Org. Chem.* **1983**, *48*, 2904. For substitution of nitro in $PhCOCH{=}CHNO_2$ see: Nesmeyanov, A. N.; Rybin, L. V.; Rybinskaya, M. I. *Zh. Org. Khim.* **1966**, *2*, 991.

(23) Nasielski, R., personal communication.

(24) For examples of nitrene formation from the decomposition of vinyl azides see: Smolinsky, G.; Pryde, C. A. In "The Chemistry of the Azido Group"; Patai, S., Ed.; Wiley: Chichester, England, 1971; Chapter 10.

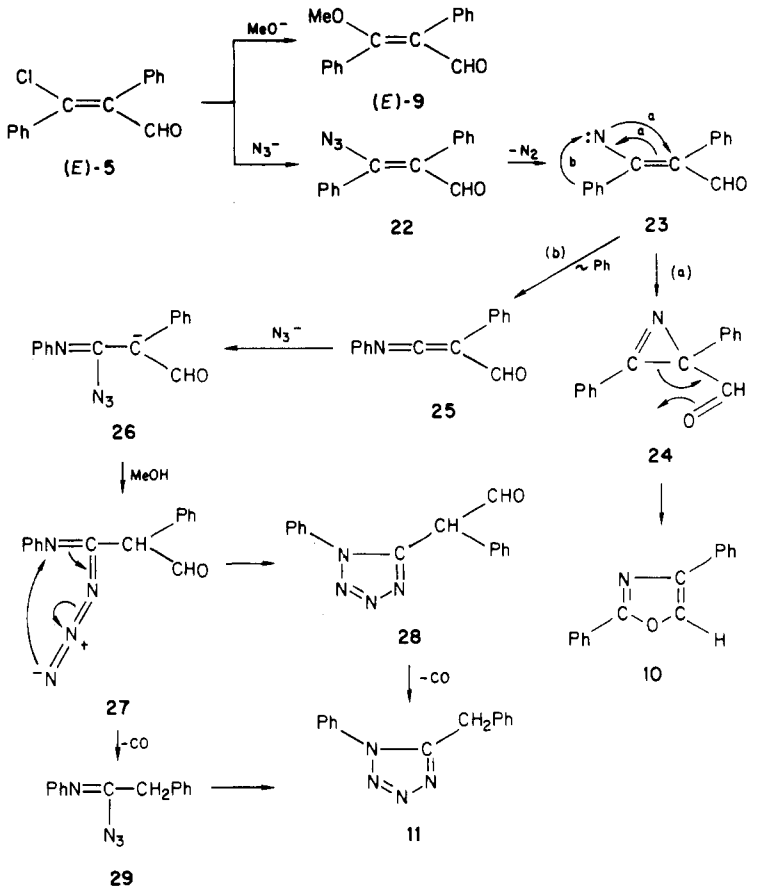
(25) For example, a recent review on oxazole chemistry includes formation of oxazoles from azirines: Turchi, I. J. *I&EC Prod. Res. Dev.* **1981**, *20*, 32.

(26) Barker, M. W.; McHenry, W. E. In "The Chemistry of Ketenes, Allenes and Related Compounds"; Patai, S., Ed.; Wiley: Chichester, England, 1980; Chapter 17.

(27) Von Braun, J.; Rudolf, W. *Chem. Ber.* **1941**, *74*, 264. Herbst, R. M.; Roberts, C. W.; Givens, H. T. F.; Harvill, E. K. *J. Org. Chem.* **1952**, *17*, 262.

(28) Carpenter, W. R. *J. Org. Chem.* **1962**, *27*, 2085.

Scheme II



1,5-bis(ethoxycarbonyl)tetrazole from diethyl diazidomalonate.[29] However, both **26** and **27** are analogues of 1,3-diketones (with C=N replacing the C=O) and initial loss of CO in the basic solution followed by cyclization is reasonable. Since we do not know if the cyclization precedes the decarbonylation or vice versa, both routes are given in Scheme II.

Interesting Features in the Solid-State Structures of (*E*)-7, (*E*)-9, 10, and 11. The interesting structural features in the structures of (*E*)-**7** and (*E*)-**9** are the torsional angles of the phenyl and the CHO groups in relation to the double bond plane, and the twist angle of the double bond. In both compounds the carbonyl group is almost planar with the double bond plane. The C(2)–C(1)–C(3)–O angles are 177.1° and 178.1°, respectively. The twist of the double bond in **10** defined by the S–C(2)–C(10) and the C(3)–C(1)–C(4) planes is 5.48° and the torsional angles of the phenyl groups from the double bond plane are −68.90° (α-Ph) and 104.07° (β-Ph). In (*E*)-**9** the twist angle of the double bond is 6.94° and the torsional angles are −133.64° (α-Ph) and 70.46°. Consequently, the phenyl groups are twisted extensively, especially the β-ring, from the double bond plane. Any assignment which is based on the λ_{max} and ϵ values for the $\pi \rightarrow \pi^*$ transition of the α,β-unconjugated aldehyde should take this into consideration.

If the plane of the five-membered ring is taken as the reference plane the torsional angles of the C-2 and the C-4 phenyl ring of **10** are 11.19° and 9.02°, respectively. The angle between the planes of the two phenyl groups is 7.07°, since C-6 and C-12 are below the reference plane by 0.026 Å and 0.012 Å, respectively.

Another interesting feature are the angles between the phenyl groups and the five-membered ring. Two angles are normal, O–C(2)–C(6) (120.0 (8)°) and C(5)–C(4)–C(12) (121.0 (8)°), but those closer to the nitrogen are wider being 125.9 (8)° (N–C(4)–C(12)) and 127.0 (8)° (N–C(2)–C(6)).

For **11** the torsional angle between the phenyl rings and the five-membered ring is 53.54°. Again, one angle (N(2)–N(1)–C(2)) is 120.0 (1)°, but the other angle (C(1)–N(1)–C(2)) is much wider, being 131.8 (2)°.

Experimental Section

Elemental analyses were done by The Hebrew University of Jerusalem Microanalysis Laboratory. Melting points were taken on Fischer-Johns melting point apparatus and are uncorrected. UV spectra were determined with a Gilford 2400-S and Spectronics 2000 spectrometers, IR spectra with Perkin-Elmer 157G spectrophotometer, and ^{1}H NMR spectra were recorded on Bruker WH-300 pulsed FT spectrometer in $CDCl_3$ unless otherwise indicated. Chemical shifts are reported in ppm downfield from internal Me_4Si signal. Electron impact mass spectra were recorded on MAT 311 instrument.

Chromatography columns were packed with Merck 35-70 silica gel or dry silica (Woelm-Pharma) and eluted with hexane, hexane–CH_2Cl_2, CH_2Cl_2, and CH_2Cl_2–CH_3OH successively. Solvents obtained from Frutarom were used without purification. TLC was taken with Merck silica gel GF_{254} plates (0.25-mm thickness).

Desoxybenzoin and diphenylacetylene were purchased from Aldrich.

Workup means diluting with H_2O, extracting with CH_2Cl_2, drying the organic phase with $MgSO_4$, filtering, and evaporating to dryness.

X-ray Crystal Structure Analysis. Data for compounds (*E*)-**7**, (*E*)-**9** and **11** were measured on a PW1100/20 Philips four-circle computer-controlled diffractometer at room temperature. Mo K_α (λ 0.71069 Å) radiation with a graphite crystal monochromator in the incident beam was used. The unit cell dimensions were obtained by a least-squares fit of 24 centered reflections in the range of $10° \leq \theta \leq 14°$. Intensity data were

(29) Moriarty, R. M.; Kliegman, J. M.; Shovlin, C. *J. Am. Chem. Soc.* **1967**, *89*, 5958; *Ibid.* **1968**, *90*, 5948.

collected by using the $\omega - 2\theta$ technique to a maximum 2θ of 50°. The scan width, $\Delta\omega$, for each reflection was 1° with a scan time of 20 s. Background measurements were made for other 20 s at both limits of each scan. Three standard reflections were monitored every 60 min. No systematic variations in intensities were found.

Intensities were corrected for Lorentz and polarization effects. All nonhydrogen atoms were found by using the results of the Multan direct method analysis.[30] After several cycles of refinements[31] the positions of the hydrogen atoms were found and added to the refinement process. Refinement proceeded to converge by minimizing the function $\sum W(|F_o| - |F_c|)^2$, where the weight, W, is $\sigma(F)^{-2}$. A final difference Fourier synthesis map showed several peaks less than 0.2 Å^{-3} scattered about the unit cell without a significant feature.

The discrepancy indices, $R = \sum ||F_o| - |F_c|| / \sum |F_o| = R_w = [\sum W(|F_o| - |F_c|)^2 / \sum W|F_o|]^{1/2}$ are presented below.

Data for **10** were measured at −155 °C on an Enraf-Nonius CAD-4 automatic diffractometer. Mo K_α (λ 0.71069 Å) radiation with a graphite crystal monochromator in the incident beam was used. The standard CAD-4 centering, indexing, and data collection programs were used. The unit cell dimensions were obtained by a least-squares fit of 22 centered reflections in the range of $10° \leq \theta \leq 15°$.

Intensity data were collected using the $\omega - 2\theta$ technique to a maximum 2θ of 50°. The scan width, $\Delta\omega$, for each reflection was $0.80 + 0.35 \tan\theta$. An aperature with a height of 4 mm and a variable width, calculated as $(2 + \tan\theta)$ mm, was located 173 mm from the crystal. Reflections were first measured with a scan of 8.24°/min. The rate for the final scan was calculated from the preliminary scan results so that the ratio $I/\sigma(I)$ would be at least 40 and the maximum scan time would not exceed 60 s. If in a preliminary scan $I/\sigma(I) > 40$, this measurement was used as the datum. Scan rates varied from 1.26 to 8.24°/min. Of the 96 steps in the scan, the first and the last 16 steps were considered to be background. During data collection the intensities of three standard reflections were monitored after every hour of X-ray exposure. No decay was observed. In addition, three orientation standards were checked after 100 reflections to check the effects of crystal movement. If the standard deviation of the H, K, and L values of any orientation reflection exceeded 0.08, a new orientation matrix was calculated on the basis of the recentering of the 22 reference reflections. The refinements were performed as described above. Data are given in Tables II, IV, and S1–S16.

Crystallographic Data. (*E*)-**7**: $C_{22}H_{18}OS$; space group $P2_{1/c}$, a = 12.789 (3) Å, b = 9.504 (2) Å, c = 15.729 (3) Å, β = 110.81 (6)°, V = 1787.1 (8) Å^3, Z = 4, ρ_{calcd} = 1.23 g cm^{-3}; μ(Mo K_α) = 1.46 cm^{-1}; no. of unique reflections 3047, reflections with $I \geq 3\sigma(I)$ = 2234; R = 0.053; R_w = 0.074.

(*E*)-**9**: $C_{16}H_{14}O_2$; space group $P\bar{1}$, a = 8.707 (2) Å, b = 9.615 (3) Å, c = 7.736 (2) Å, α = 95.91 (6)°, β = 99.55 (5)°, γ = 85.52°, V = 634.0 (5) Å^3, Z = 2, ρ_{calcd} = 1.248 g cm^{-3}, μ(Mo K_α) = 0.46 cm^{-1}; no. of unique reflections 2725, reflections with $I \geq 3\sigma(I)$ 2213, R = 0.049, R_w = 0.077.

(*E*)-**10**: $C_{15}H_{11}NO$; space group $P2_12_12_1$, a = 11.147 (4) Å, b = 17.545 (6) Å, c = 5.692 (2) Å, V = 1113.2 (8) Å^3, Z = 4, ρ_{calcd} = 1.320 g cm^{-3}, μ(Mo K_α) = 0.46 cm^{-1}; no. of unique reflections 1138, reflections with $I \geq 2\sigma(I)$ = 1066, R = 0.0972.

(*E*)-**11**: $C_{14}H_{12}N_4$; space group $P2_1/n$, a = 13.190 (3) Å, b = 8.072 (2) Å, c = 11.410 (3) Å, β = 96.64 (8)°, V = 1206.7 (6) Å^3, Z = 4, ρ_{calcd} = 1.30 g cm^{-3}, μ(Mo K_α) = 0.47 cm^{-1}; no. of unique reflections 2099, reflections with $I \geq 3\sigma(I)$ = 1598, R = 0.041, R_W = 0.055.

(*E*)-β-Chloro-α-phenylcinnamaldehyde ((*E*)-5). (a) To an ice-cooled mixture of DMF (15 mL) and trichloroethylene (150 mL) was added $POCl_3$ (8.5 mL, 90 mmol) dropwise with stirring which continued for additional 30 min at room temperature after the addition. Desoxybenzoin (12 g, 60 mmol) was then added and stirring continued for 5 h at 90 °C and 18 h at 20 °C. NaOAc (30 g, 366 mmol) in water (50 mL) was added and the mixture was poured after 30 min stirring into water (500 mL), extracted with CH_2Cl_2 (2 × 100 mL), separated, dried, and evaporated. NMR of the crude remainder showed 40% of unreacted desoxybenzoin, 50% of (*E*)-β-chloro-α-phenylcinnamaldehyde (*E*)-**5** and ca. 10% of the *Z* isomer (*Z*)-**5**. Crystallization of the oily solid from EtOH gave a white solid, mp 145 °C (4.75 g, 32%), whose spectral data are given in Table I, and which is identical with (*E*)-**5** (lit.[10] mp 146–147 °C, λ_{max} 283 nm (ε 9000), δ 9.59) obtained by Weissenfels et al. from a similar reaction. Attempts to isolate (*Z*)-**5** from the reaction failed.

(b) The reaction was repeated by using desoxybenzoin (12 g, 60 mmol) and stirring for 30 h at 90 °C. The crude product contained a 40:60 mixture of (*Z*)-**5** to (*E*)-**5** and traces of desoxybenzoin. Recrystallization (EtOH) gave (*E*)-**5** (3.5 g, 24%). The mother liquer contained 75% of (*Z*)-**5**. It was combined with the irradiation solution of (*E*)-**5** and chromatographed on silica gel and the fraction rich in (*Z*)-**5** was crystallized from hexane, giving (*Z*)-**5** (4 g, 95%), mp 79 °C (lit.[10] mp 82 °C, λ_{max} 298 nm (ε 7200), δ 10.46), admixed with 3% of (*E*)-**5** and 2% of 9-chlorophenanthrene-10-carboxaldehyde.

Isomerization of (*E*)-5 to (*Z*)-5. (a) A stirred solution of the (*E*)-**5** (2 g, 8.3 mmol) in dry benzene (200 mL), to which argon gas was constantly bubbled, was irradiated with a Hanovia medium-pressure 450-W lamp. After 10 and 52 h, the NMR showed (*E*)-**5**/(*Z*)-**5** ratios of 9:1 and 7:3, respectively, but signals in the aromatic region for 9-chloro-10-phenanthrenecarboxaldehyde **6** were not observed. Chromatography on a 50 × 3 cm silica gel column, with 30% $CHCl_3$–70% hexane as the eluent gave two fractions. (i) A yellow solid (120 mg, 6%). Trituration with benzene gave a white solid, mp 147 °C (30 mg, 1.5%), identified as **6**, by the similarity of its UV and NMR spectra to those of phenanthrene: R_f (1:1 CH_2Cl_2–hexane) 0.8. λ_{max} (EtOH) 226 sh nm (ε 22 200), 247 sh (51 500), 252 (52 400), 263 sh (40 000), 287 (12 400), 323 (13 600), 370 sh (2600); ν_{max} (CCl_4) 1665 cm^{-1}; δ ($CDCl_3$) 7.66–7.85 (4 H, m, Ar), 8.56–8.69 (3 H, m, Ar), 8.99–9.02 (1 H, m, Ar), 11.04 (1 H, s, CHO). Irradiation at 7.7 ppm simplified the pattern in the aromatic region. MS, m/z 242, 240 (100, M), 214, 212 (32, 97, M − CO), 205 (25, M − Cl), 176 (99, M − Cl − CHO), 150 (20), 126 (5), 111 (7), 106 (8), 102 (9). Anal. Calcd for $C_{15}H_9ClO$: C, 74.84; H, 3.74; Cl, 14.76. Found: C, 75.10; H, 3.81; Cl, 14.56. (ii) A white solid (1 g, 50%) which by NMR is a 3.2:1 mixture of (*Z*)-**5** (R_f in 1:1 CH_2Cl_2–hexane 0.6) to (*E*)-**5** (R_f 0.55). Separation was achieved by recrystallization from hexane. The more soluble (*Z*)-**5**, mp 75 °C, was obtained from the mother liquor (0.5 g, 25%). λ_{max} (EtOH) 226 nm (ε 2600), 246 (4400), 254 sh (4000), 260 sh (3600), 298 (6600); ν_{max} (CCl_4) 2900, 2840, 1680 (C=O), 1580–1510, 1440, 1290, 1090, 1030 cm^{-1}; δ ($CDCl_3$) 6.96–7.26 (10 H, m, Ar), 10.60 (1 H, s, CHO).

(b) A solution of (*E*)-**5** (470 mg, 1.93 mmol) in cyclohexane (100 mL) was irradiated with 4 × 15 W lamps in Rayonet reactor at 254 Å with constant nitrogen bubbling. After 21, 48, and 68 h the (*E*)-**5**/(*Z*)-**5**/**6** ratios were 60:40:0, 58:35:7, and 55:31:12, respectively. Evaporation of the solvent and crystallization from hexane gave the pure (*Z*)-**5** (60 mg, 13%).

Reactions of (*E*)-5 with Nucleophiles. (a) With *p*-Toluenethiolate Ion. (*E*)-α-Phenyl-β-(*p*-tolylthio)cinnamaldehyde ((*E*)-7). (i) To a solution of (*E*)-**5** (1 g, 4 mmol) in DMF (100 mL) was added a freshly prepared (from NaH and *p*-toluenethiol) sodium *p*-toluenethiolate (0.58 g, 4 mmol). The mixture was stirred for 24 h at room temperature, poured into 1 N HCl (100 mL), extracted rapidly with $CHCl_3$ (2 × 25 mL), and the organic phase was dried and evaporated. The ^{1}H NMR of the remainder showed the presence of only (*E*)-**5** and (*E*)-**7** in a 46:54 ratio. Chromatography on silica with hexane–CH_2Cl_2 as the eluant gave 0.35 g (35%) of (*E*)-**5** and 0.45 g (35%) of a solid which on recrystallization from ethanol gave 0.31 g (43% based on the (*E*)-**5** reacted) of pale yellow crystals of (*E*)-α-phenyl-β-*p*-tolylthiocinnamaldehyde, (*E*)-**7**: mp 105 °C; UV and NMR spectra are given in Table I; ν_{max} ($CHCl_3$) 2950 (C–H), 1650 (C=O) 1545, 1490, 1290, 1080 cm^{-1}; MS, m/z 330 (20, M), 313 (14, M − OH), 239 (10, M − C_7H_7), 236 (15, M − OH − Ph), 178 (B, M − CHO − SC_6H_4Me), 155 (10), 124 (6, MeC_6H_4S), 91 (11, $C_7H_7^+$). Anal. Calcd for $C_{22}H_{18}OS$: C, 79.96; H, 5.49. Found: C, 80.12; H, 5.73.

(30) Main, P.; Hull, S. E.; Lessinger, L.; Germain, G.; Declercq, J. P.; Woolfson, M. M. Multan 78. A system of computer programs for the automatic solution of crystal structures from X-ray diffraction data, Universities of York, England, and Louvain, Belgium.

(31) All crystallographic computing was done on a Cyber 74 computer at the Hebrew University of Jerusalem with the Shelx 1977 structure determination package.

(ii) The experiment was repeated by using a solution of (*E*)-**5** (180 mg, 0.75 mmol) in DMF (20 mL) and adding sodium *p*-toluenethiolate in several portions over 47 h. Aliquots were taken out on each addition, worked up as above, and analyzed by NMR. In all the experiments only (*E*)-**5** and (*E*)-**7** were observed. Their ratio changed from 1:1 after 7 h ([(*E*)-**5**]/[salt] ratio = 1.5) to 55:45 and to 100:0 after 23 and 47 h, respectively.

(iii) To a solution of (*E*)-**5** (0.49 g, 2 mmol) in DMF (5 mL) was added six month old sodium *p*-toluenethiolate (0.38 g, 2.6 mmol) and the mixture was stirred for 22 h at room temperature. Workup as above gave a mixture which by ^{1}H NMR consisted of a 50:25:25 of (*E*)-**5** to (*E*)-**7** to a new compound which is assumed to be (*Z*)-**7** (see text), respectively. On standing for 2 days in $CDCl_3$ at 25 °C, the (*E*)-**7**/(*Z*)-**7** ratio changed to 57:43. Separation on a PLC plate gave an oily solid which was a 2:1 (*E*)-**7**/(*Z*)-**7** mixture. Recrystallization from ethanol gave 85% of the pure (*Z*)-**7** admixed with 15% (*E*)-**7**: mp of the mixture 70 °C; UV and NMR data are in Table I; ν_{max} ($CHCl_3$) 2950 (C–H), 1655 (C=O), 1550, 1480, 1300, 1090 cm^{-1}; MS, *m/z* 330 (22, M), 313 (6, M – OH), 301 (2, M – CHO), 224 (4, M – Ph – CHO), 207 (4, M – SC_6H_4Me), 178 (B, M – SC_6H_4MeCHO), 153 (6), 124 (5, MeC_6H_4SH), 106 (9), 91 (7, $C_7H_7^+$). Anal. Calcd for $C_{12}H_{18}OS$: C, 79.96; H, 3.49. Found: C, 80.19; H, 5.61.

(b) With *p*-Cresolate Ion. (*E*)-α-Phenyl-β-(*p*-methylphenoxy)cinnamaldehyde ((*E*)-8). To a solution of (*E*)-**5** (610 mg, 2.5 mmol) in DMF (10 mL) was added sodium *p*-cresolate (350 mg, 2.7 mmol). The mixture turned red and then yellow after 1 h. After stirring for 26 h at room temperature, it was poured into 1 N HCl solution (100 mL) and extracted with $CHCl_3$ (2 × 25 mL) which was dried and evaporated. ^{1}H NMR showed a 45:55 ratio of (*E*)-**5** to (*E*)-**8** but no (*Z*)-**8**. On trituration with ethanol (*E*)-**5** (150 mg) was recovered. The mother liquor was evaporated and recrystallized twice from ethanol giving white plates (160 mg, 20%), mp 139 °C, of (*E*)-**8**: UV and NMR data are in Table I; ν_{max} (CCl_4) 1670 (C=O), 1600–1530, 1500, 1315, 1210, 1080 cm^{-1}; MS, *m/z* 314 (35, M), 299 (3, M – Me), 298 (10, M – CH_4), 178 (B, Ph_2C_2), 152 (8), 108 (13), 105 (50, PhCO). Anal. Calcd for $C_{22}H_{18}O_2$: C, 84.07; H, 5.73. Found: C, 84.24; H, 5.74.

(c) With Methoxide Ion. α-Phenyl-β-methoxycinnamaldehydes ((*E*)- and (*Z*)-9). (*E*)-**5** (0.73 g, 3 mmol) was added to a solution of NaOMe (250 mg, 4.6 mmol) in MeOH (250 mL). The suspension was stirred for 3 h at room temperature until an homogeneous solution was obtained and TLC revealed only traces of the starting material. After 5 h the mixture was poured into a 1 N HCl solution (50 mL), extracted with CH_2Cl_2, and dried ($MgSO_4$) and the solvent was evaporated giving a white solid. ^{1}H NMR showed the presence of two isomers in a 9:1 ratio and no (*E*)-**5**. Recrystallization from ethanol gave white crystals, mp 133 °C (0.4 g, 56%), of (*E*)-**9**. UV and NMR data are in Table I; ν_{max} (CCl_4) 2920 (C–H), 2840 (C–H), 1665 (C=O), 1580, 1540, 1440, 1300, 1280, 1080 cm^{-1}; MS, *m/z* 238 (B, M), 223 (19, M – Me), 207 (10, M = MeO), 194 (14, M – Me – CHO), 178 (41, Ph_2C_2), 165 (31), 152 (11), 105 (34, PhCO). Anal. Calcd for $C_{16}H_{14}O_2$: C, 80.57; H, 5.88. Found: C, 80.30; H, 6.15. The crude mixture shows additional signals at 3.64 (3 H, s, MeO), 6.90–7.30 (10 H, m, Ar), and 10.48 (1 H, s, CHO) which were ascribed to (*Z*)-**9**. Those at 3.64 and 10.48 had intensities of ca. 10% of those of the corresponding signals of (*E*)-**9**.

(d) With EtOH. (*E*)-**5** (0.14 g, 0.57 mmol) was refluxed in EtOH (10 mL) for 6 h. After evaporation of the solvent only (*E*)-**5** was recovered as determined by TLC, NMR, and melting point.

(e) With Azide Ion. To a solution of (*E*)-β-chloro-α-phenylcinnamaldehyde (2.8 g, 11.5 mmol) in acetonitrile (50 mL)–methanol (50 mL) was added sodium azide (2 g, 30 mmol). The yellow suspension which became light red was stirred for 46 h at room temperature, poured on water (100 mL), extracted with $CHCl_3$ (3 × 50 mL), separated, and dried ($MgSO_4$). On evaporation of the solvent an orange oily solid (2.2 g) was obtained. TLC showed the absence of the starting material and IR showed the absence of RN_3 absorption at 2100 cm^{-1}. Chromatography on silica gel with hexane–$CHCl_3$ as the eluant gave three compounds.

(a) White solid (0.45 g, 17%), which after crystallization from EtOH gave white needles: mp 96 °C (0.22 g, 8%); R_f (CH_2Cl_2–hexane) 0.7; λ_{max} (EtOH) 232 nm (ε 17 000), 238 sh (16 000), 263 (15 600), 270 sh (16 000), 275 (16 600), 292 sh (13 400); ν_{max} (CCl_4) 3020, 2900, 1530, 1485 cm^{-1}; ^{1}H NMR δ ($CDCl_3$) 7.40–8.13 (m); MS, *m/z* 221 (B, M$^+$), 193 (65, M – CO?), 165 (14), 110 (3), 90 (44), 89 (50), 63 (15). Anal. Calcd for $C_{15}H_{11}NO$: C, 81.44; H, 4.97; N, 6.33. Found: C, 81.50; H, 5.50; N, 5.70.

X-ray crystallography showed a five-membered heterocycle with phenyl subsituents in 1,3-positions, which was identified as 2,4-diphenyloxazole (**10**).

(b) White crystals from EtOH (70 mg, 3%): mp 140 °C; R_f (CH_2Cl_2) 0.4; ^{1}H NMR δ ($CDCl_3$) 3.49 (3 H, s, MeO), 7.32–7.54 (10 H, m, Ph), 9.36 (1 H, s, CHO); MS, *m/z* 239 (M$^+$, 70), 237 (M – 2H, 100), 222 (M – OH, 23), 206 (M – H – MeOH, 14.6), 194 (M – 2H – MeCO, 25), 178 (PhC≡CPh, 86), 105 (PhCO$^+$, 42). Anal. Calcd for $C_{15}H_{14}O_2$: C, 80.67; H, 5.88. Found: C, 80.56; H, 5.95.

The compound was identified by X-ray crystallography as (*E*)-β-methoxy-α-phenylcinnamaldehyde. Its IR and NMR spectra are consistent with those of (*E*)-**9**, formed as the main product by reaction of (*E*)-**5** with sodium methoxide.

(c) Yellow crystals (0.4 g, 15%), mp 125 °C, after crystallization from EtOH: R_f (CH_2Cl_2) 0.3; ν_{max} (nujol) 1600 (m) (C–NH_2), 1500 (s) cm^{-1}; ^{1}H NMR δ ($CDCl_3$) 4.27 (2 H, s), 7.09, 7.24, 7.53 (10 H, m, Ar); MS, *m/z* (high resolution) 236.1061 ($C_{14}H_{12}N_4$), 207.0892 (M – HN_2, $C_{14}H_{11}N_2$); MS, *m/z* (EI) 236 (2.5, M), 207 (2.5, M – HN_2), 91 (100, $C_7H_7^+$); MS, *m/z* (CI, 120 °C, $C_4H_9^+$) 473 (0.1, 2M + H), 293 (4, M + $C_4H_9^+$), 237 (100, MH$^+$), 209 (4, MH – N_2), 119 (13).

The compound was identified as 1-phenyl-5-benzyltetrazole by X-ray crystallography. Anal. Calcd for $C_{14}H_{12}N_4$: C, 71.19; H, 5.08; N, 23.73. Found: C, 71.33; H, 5.36; N, 22.90.

(f) With Chloride Ion. A mixture of (*E*)-**5** (13.5 mg, 0.054 mmol) and dry tetrabutylammonium chloride (33.4 mg, 0.12 mmol) in $CDCl_3$ (0.5 mL) was kept at room temperature without protection from daylight. ^{1}H NMR analysis of samples taken after 42 and 267 h showed the presence of (*E*)-**5**/(*Z*)-**5** mixtures containing 3% and 23% of (*Z*)-**5**, respectively. An identical control experiment except for the absence of the ammonium salt showed the presence of 23–24% (*Z*)-**5** after 90–117 h.

When the same experiment was repeated for 140 h in the dark in the absence of added Bu_4NCl, ≤2% of (*Z*)-**5** were formed, and in the presence of 1.8 mol equiv of Bu_4NCl to (*E*)-**5** no (*Z*)-**5** was observed after 110 h.

Reaction of (*Z*)-5 with Nucleophiles. (a) With Sodium *p*-Toluenethiolate. A mixture of (*Z*)-**5** (1.25 g, 5 mmol), and sodium *p*-toluenethiolate (0.9 g, 6 mmol) in DMF (15 ml) was stirred for 40 h at room temperature. The solution turned green. The color disappeared when the mixture was poured into aqueous 0.1 N HCl solution (100 mL), extracted with CH_2Cl_2, dried, and evaporated. An NMR spectrum of a small sample taken after 6 h showed mainly (*E*)-**7** and traces of unreacted (*Z*)-**5**. Chromatography on silica gel gave 0.4 g (23%) of (*E*)-**7** which was identical (TLC, NMR) with the product obtained from (*E*)-**5**.

(b) With Sodium *p*-Cresolate. A mixture of (*Z*)-**5** (1.25 g, 5 mmol) and sodium *p*-cresolate (0.8 g, 6 mmol) in DMF (15 mL) was stirred at room temperature for 48 h. The red solution was poured into water (100 mL), extracted with CH_2Cl_2 (50 mL), dried, and evaporated. NMR analysis of the crude product after 6 and 48 h showed the presence of a 7:3 (*E*)-**8**/(*Z*)-**8** mixture. Chromatography over silica, with hexane–CH_2Cl_2 as the eluant, gave the unreacted starting material (0.4 g, 32%), pure (*E*)-**8** (0.32 g, 13%), mp 130 °C, and a 4:6 (*E*)-**8**/(*Z*)-**8** mixture (0.21 g, 13%). Crystallization of the last fraction from ethanol gave pure (*E*)-**8** (45 mg, 3%), mp 130 °C. Recrystallization of the evaporated mother solution which showed a 85:15 (*Z*)-**8**/(*E*)-**8** ratio gave white crystals, mp 85 °C (55 mg, 3%), of (*Z*)-**8**: UV and NMR data are in Table I; ν_{max} (CCl_4) 2960, 1675 (C=O), 1500, 1230, 1200 cm^{-1}. Anal. Calcd for $C_{22}H_{18}O_2$: C, 84.07; H, 5.73. Found: C, 83.97; H, 5.89.

(c) With Sodium Methoxide. A solution of a 96% pure (*Z*)-**5** (0.5 g, 2.5 mmol) in MeOH (20 mL) containing NaOMe (216 mg, 4 mmol) was stirred at room temperature in the dark for 40 h. The mixture was poured into water (100 mL) and extracted with CH_2Cl_2 (2 × 50 mL), and the organic phase was dried and evaporated. NMR of the crude product showed a 96:4 mixture of (*E*)-**9** to (*Z*)-**9**. Crystallization from EtOH gave pure (*E*)-**9** (510 mg, 74%), mp 136 °C.

Stability of (*E*)-9 in NaOMe. A solution of (*E*)-**9** (60 mg, 0.25 mmol) in MeOH (3 mL) containing sodium methoxide (18

mg, 0.3 mmol) was stirred for 5 h at room temperature. After pouring into water (20 mL), extracting with $CHCl_3$ (10 × 2 mL), drying, and evaporation of the solvent, TLC and NMR showed the presence of only (*E*)-**9**, with no trace of (*Z*)-**9**. Crystallization from ethanol gave (*E*)-**9** (30 mg, 50% recovery), mp 129 °C.

Reaction of (*E*)-3 with Sodium Methoxide. A solution of (*E*)-**3** (1 g, 2.8 mmol) and NaOMe (4.3 mmol, prepared from 100 mg (4 mmol) of Na) in MeOH (3 mL)–MeCN (50 mL) was stirred in the dark at room temperature for 140 h. It was then poured into 1 N HCl (100 mL), extracted with $CHCl_3$ (2 × 50 mL), and the organic phase was separated, washed with $Na_2S_2O_3$ solution and then with water, dried, and evaporated. The ^1H NMR showed two MeO signals in 7:3 ratio. If the low field signal is ascribed to a MeO trans to a phenyl group then the products are 7:3 (*Z*)-**12** to (*E*)-**12**. Few additional small MeO signals were observed. Crystallization from cyclohexane gave, as a first fraction, white crystals (30 mg, 4%) mp 203 °C, of 1,2-dimethoxy-1,2-diphenylethylene **13**: λ_{max} (EtOH) 224 nm (ϵ 8900), 255 sh (3600); δ ($CDCl_3$) 3.27 (3 H, s, MeO), 6.90–6.94 (2 H, m, Ar), 7.22–7.32 (6 H, m, Ar), 7.47–7.50 (2 H, m, Ar); MS, *m/z* 240 (3, M), 165 (10), 151 (100), 105 (63, $PhCO^+$), 91 (11, $C_7H_7^+$), 77 (44, Ph). Anal. Calcd for $C_{16}H_{16}O_2$: C, 80.00; H, 6.66. Found: C, 80.24; H, 6.82.

Slow crystallization of the remainder (0.41 g, 56%) from cyclohexane or EtOH and further crystallization from CH_2Cl_2 gave long crystals, mp 82 °C, 6:4 (*Z*)-**12** to (*E*)-**12**. The solid obtained from EtOH, mp 83 °C, has the following characteristics: TLC (silica) 6:4 CH_2Cl_2–hexane) R_f 0.45; HPLC R_f 7.0 min (silica 60, CH_2Cl_2, F = 1.0, UV = 254); the two isomers were not separated; λ_{max} (EtOH) 246 sh nm (ϵ 5800), 267 (7300); δ ($CDCl_3$) 3.47 ((*E*)-**12**), 3.60 ((*Z*)-**12**) [3 H, 2 s, MeO, 7:3 ratio], 7.13–7.47 (10 H, m, Ar); MS, *m/z* 255 (85, M), 194 (91, M – NO – OMe), 180 (18, M – NO – OMe – CH_2), 166 (82, M – NO – COOMe), 165 (86, M – NO_2 – Me – CO), 151 (9), 136 (14), 119 (22, $PhCOCH_2$), 105 (100, PhCO). Anal. Calcd for $C_{15}H_{13}NO_3$: C, 70.58; H, 5.19; N, 5.49. Found: C, 70.48; H, 5.36; N, 5.08.

When the same reaction was conducted in MeOH for 24 h, to which MeCN was added, and the reaction continued for an additional 24 h, only (*E*)-**3** was recovered, and traces of the product were observed.

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Registry No. (*E*)-**3**, 55902-54-0; (*E*)-**5**, 50460-72-5; (*Z*)-**5**, 19881-68-6; **6**, 52979-79-0; (*E*)-**7**, 96746-49-5; (*Z*)-**7**, 96746-50-8; (*E*)-**8**, 96746-51-9; (*Z*)-**8**, 96746-55-3; (*E*)-**9**, 96746-52-0; (*Z*)-**9**, 96746-53-1; **10**, 838-41-5; **11**, 96746-54-2; (*E*)-**12**, 96746-56-4; (*Z*)-**12**, 96746-57-5; **13**, 30928-28-0; NaOMe, 124-41-4; desoxybenzoin, 451-40-1; sodium *p*-toluenethiolate, 657-84-1; sodium *p*-cresolate, 1121-70-6; sodium azide, 26628-22-8; tetrabutylammonium chloride, 1112-67-0.

Supplementary Material Available: Tables S1–S16 giving the crystallographic data (bond lengths and angles, positional, and thermal parameters) for (*E*)-**7**, (*E*)-**9**, **10** and **11** and Figures S1–S4 giving their stereoscopic views (26 pages). Ordering information is given on any current masthead page.

Photooxygenation of Acetone Hydrazone: Characterization of an Unstable Intermediate

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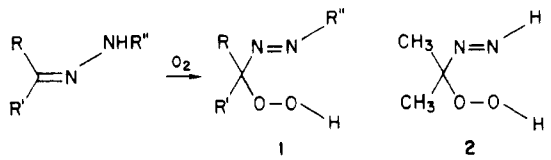
The tetraphenylporphyrin-sensitized photooxygenation of acetone hydrazone produces 2–4% of an unstable compound with a ^1H NMR spectrum consisting of singlets at 1.3 (6 H), 13.7 (1 H), and 15.8 (1 H) ppm. The structure assigned is that of the hydroperoxy diazene (azo hydroperoxide) $(CH_3)_2C(OOH)N{=}NH$. The compound decomposes very rapidly above −20 °C with a high yield of formation of N_2 but no O_2 ($[N_2]:[O_2] > 100:1$). Photooxygenation of either acetone hydrazone or benzophenone hydrazone in toluene gives 10–20% yields of cresols.

The photosensitized oxygenation of hydrazones leads to α-azo hydroperoxides **1**.[1,2] These compounds are of interest as radical initiators,[3] as oxidizing agents,[4-6] and as a source of the hydroxyl radical in anhydrous organic media.[7-9] A number of other aspects of their chemistry have been studied, including their structure and spectra,[10-18] formation via autoxidation,[18-20] formation via reaction pathways involving singlet oxygen,[21-23] reactions



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