finding here, the activation energy for initiation of styrene by *n*-butyllithium in benzene solution is reported to be greater than that for propagation.[32] The activation energy for initiation of isoprene by *n*-butyllithium in diethyl ether is also reported to be greater than that for propagation;[33] however, the situation is reversed in heptane.[34]

The organolithium reagents, owing to the relatively high concentration used in these experiments, no doubt exist as ion pairs or clusters of ion pairs in which the incipient lithium cation is expected to be strongly solvated. The transition state for olefin addition under these conditions is presumed to be of the four-center type involving stretching of the carbon–lithium bond while simultaneously forming new carbon–carbon and carbon–lithium bonds.

It is known that organolithium compounds are associated in hydrocarbon solution[35] and this has been shown to affect the kinetics of their reactions.[32,36] Kinetic behaviors of some organolithium compounds in THF solution[37,38] suggest the alkyl and sp^2-type species may be aggregated in this solvent, whereas other species such as benzyl and allyl are indicated to be monomeric.[38] Aggregation of the organolithium compounds in THF solution is thus indicated to differ for different structure types. Assuming that the aggregate must be disrupted prior to or during the reaction, both the extent and energy of clustering would be a critical factor influencing the relative reactivities of these species.

The relative reactivities determined in this study, thus, represent *effective* reactivities characteristic of the respective organolithium species. Equating the measured reactivities with inherent reactivities characteristic of the organic moiety, with the exclusion of other structure dependent variables, must take possible differences in solution properties into account. This will require detailed kinetic and solution property studies, which are in progress.

Registry No.—*t*-Butyllithium, 594-19-4; *sec*-butyllithium, 598-30-1; ethyllithium, 811-49-4; *n*-butyllithium, 109-72-8; α-methylbenzyllithium, 13950-05-5; crotyllithium, 13950-06-6; benzyllithium, 766-04-1; allyllithium, 3052-45-7; *p*-tolyllithium, 2417-95-0; yllithium, 591-51-5; phenyllithium· LiCl, 13950-09-9; phenyllithium· LiBr, 13950-10-2; methyllithium, 917-54-4; vinyllithium, 917-57-7; triphenylmethyllithium, 13950-11-3; THF, 109-99-9.

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[32] D. J. Worsfold and S. Bywater, *Can. J. Chem.*, **38**, 1891 (1960).

[33] H. Sinn and F. Banderman, IUPAC Meeting, Prague, 1965, Preprints, p 575.

[34] H. Sinn, C. Lundborg, and O. L. Onsager, *Macromol. Chem.*, **70**, 222 (1963).

[35] D. Margerison and J. P. Newport, *Trans. Faraday Soc.*, **59**, 2053 (1963); T. L. Brown and M. T. Rogers, *J. Am. Chem. Soc.*, **79**, 1859 (1957).

[36] K. F. O'Driscoll and A. V. Tobolsky, *J. Polymer Sci.*, **35**, 259 (1959); A. G. Evans and D. B. George, *J. Chem. Soc.*, 4653 (1961); D. J. Worsfold and S. Bywater, *Can. J. Chem.*, **38**, 1891 (1960). Other references cited in ref 37 and 38.

[37] R. Waack and P. E. Stevenson, *J. Am. Chem. Soc.*, **87**, 1183 (1965).

[38] R. Waack and P. West, *J. Organometal. Chem.* (Amsterdam), **5**, 188 (1966).

Epoxidation of Alkylidenecyanoacetic Esters with Hydrogen Peroxide and Related Reactions[1]

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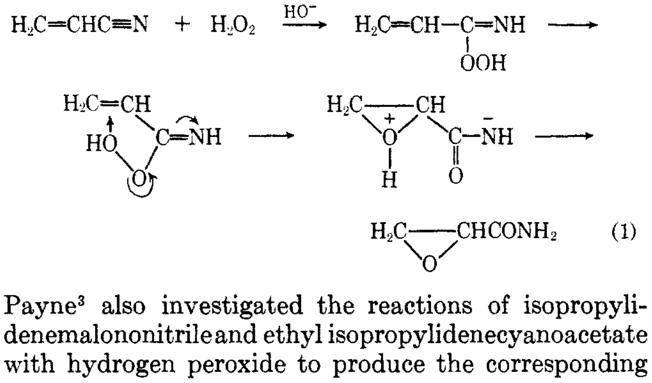
The reaction mechanism of alkylidenecyanoacetic esters with hydrogen peroxide in the presence of sodium tungstate or trisodium phosphate is discussed. It is concluded that the first step is the nucleophilic attack of the pertungstate anion (or perhydroxyl anion in the case of phosphate catalysis) on the double bond to give the corresponding epoxy nitrile, hydrolysis of which with alkaline hydrogen peroxide gives the epoxy amide. The fact that an epoxy nitrile intermediate was detected supports this view.

Payne and Williams[2] studied the base-catalyzed reaction of acrylonitrile with hydrogen peroxide to give glycidamide and proposed the mechanism shown in eq 1.



(1)

Payne[3] also investigated the reactions of isopropylidenemalononitrile and ethyl isopropylidenecyanoacetate with hydrogen peroxide to produce the corresponding epoxy amides (along with some epoxy nitriles). It seems, however, that the mechanism for the reaction of basic hydrogen peroxide with ethyl isopropylidenecyanoacetate was not extensively studied.

In the preceding paper,[4] we studied the synthesis of the epoxy amides II from ethyl alkylidenecyanoacetates I and hydrogen peroxide in the presence of sodium tungstate or trisodium phosphate. In continuation, the mechanism of the reaction has now been studied.

Tungstate Catalysis.—Methyl 2-cyano-3-methyl-2-butenoate (Ia) reacted at 70° (1 hr) with 30% hydrogen peroxide in the presence of sodium tungstate, to give methyl 2-carbamoyl-2,3-epoxy-3-methylbutanoate (IIa) along with some methyl 2-cyano-2,3-epoxy-3-methylbutanoate (IIIa) and methyl 2-carbamoyl-3-methyl-2-butenoate (IVa). Three possible reaction courses are visualized as shown in Scheme I.

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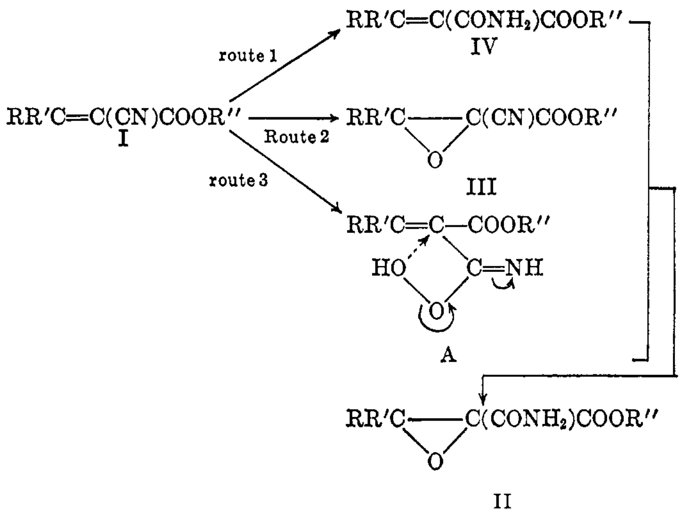
[1] This work is based partly on the doctoral dissertation of M. I., The University of Tokyo, 1966.

[2] G. B. Payne and P. H. Williams, *J. Org. Chem.*, **26**, 651 (1961).

[3] G. B. Payne, *ibid.*, **26**, 663 (1961).

[4] M. Igarashi and H. Midorikawa, *ibid.*, **28**, 3088 (1963).

SCHEME I



	R	R'	R''		R	R'	R''
a	CH_3	CH_3	CH_3	h	H	C_6H_5	C_2H_5
a'	CH_3	CH_3	C_2H_5	i	C_6H_5	C_6H_5	C_2H_5
b	CH_3	C_2H_5	C_2H_5	j	CH_3	C_6H_5	C_2H_5
c	CH_3	n-C_6H_{13}	C_2H_5	k	H	p-CH_3O-C_6H_4	C_2H_5
d	CH_3	i-C_3H_7	CH_3	l	H	m-CH_3O-C_6H_4	C_2H_5
e	CH_3	t-C_4H_9	CH_3	m	H	o-CH_3O-C_6H_4	C_2H_5
f	i-C_4H_9	i-C_4H_9	CH_3	n	H	p-NO_2-C_6H_4	C_2H_5
g	n-C_4H_9	n-C_4H_9	CH_3	o	H	o-NO_2-C_6H_4	C_2H_5
				p	H	p-HO-C_6H_4	C_2H_5

The amide IV was desired to test the possiblility of it being an intermediate in the epoxidation. Ethyl 2-carbamoyl-3-methyl-2-butenoate (IVa'), which had previously been prepared by Corey[5] from isopropylidenemalonic monoethyl ester and phosphorus pentachloride followed by ammonia, was obtained from Ia' with polyphosphoric acid. Ethyl 2-carbamoyl-3-methyl-2-pentenoate (IVb) was prepared from ethyl 1-methylpropylidenemalonate by Corey's method.

IVa' was subjected to the original reaction conditions. An 85% recovery of unchanged starting material was isolated. No other product was identified. IVb showed a similar stability toward basic hydrogen peroxide. This lack of reactivity indicates that route 1 is not an important one for the formation of II.

Another possible course to II would be *via* the epoxy nitrile III (route 2). Ia' was epoxidized by means of alkaline *t*-butyl hydroperoxide[2,3] affording IIIa' in 50% yield. In addition, ethyl 2-cyano-2,3-epoxy-3-methylnonanoate (IIIc) was obtained in 65% yield from ethyl 2-cyano-3-methyl-2-nonenoate (Ic) and cumenyl hydroperoxide.

Reaction of IIIa' with hydrogen peroxide under the original conditions gave IIa' in 72% yield, somewhat higher than the yield (61%) obtained from Ia'. Similarly, the yield of ethyl 2-carbamoyl-2,3-epoxy-3-methylnonanoate (IIc) from IIIc was higher than that of IIc from Ic (see Table I).[6] These results suggest that epoxy nitrile III is an intermediate for the formation of II from I.

Earlier work[4] indicated that a large excess of hydrogen peroxide is required for conversion of I into II. In the present work, the epoxidation was carried out with various amounts of hydrogen peroxide. With 2 molar equiv of hydrogen peroxide, Ia gave a low yield (5%) of IIa but a good yield (66%) of IIIa. The proportion of epoxy amide to epoxy nitrile was dependent on the amount of hydrogen peroxide; a larger amount of hydrogen peroxide increased the yield of epoxy amide with a decrease of epoxy nitrile (see Table II). It seems again likely that II is obtained *via* III.

It is also considered that II arises by reaction of III

TABLE I

EPOXIDATION OF I AND III IN THE PRESENCE OF SODIUM TUNGSTATE[a]

Starting material	Product	Yield, %
Ia'[b]	IIa'[c]	61
IIIa'[d]	IIa'	72
Ic[b]	IIc[c]	64
IIIc[d]	IIc	75

[a] Reaction conditions: I and III (0.1 mole), 30% H_2O_2 (0.8 mole), $Na_2WO_4 \cdot 2H_2O$ (0.05 mole), 70–80°, 1 hr. [b] See ref 18. [c] See ref 4. [d] See Experimental Section.

TABLE II

EPOXIDATION OF Ia WITH VARIOUS AMOUNTS OF HYDROGEN PEROXIDE IN THE PRESENCE OF SODIUM TUNGSTATE[a]

H_2O_2/Ia, moles/mole	Yield, %, of product[b]			
	IIa	IIIa	IVa	Ia unchanged
1.5	4	58		13
2.0	5	66		5
2.5	16	58		2
3.0	32	40	1	1
4.0	41	33	2	
6.0	57	15	2	Trace
8.0	66	4	3	
10.0	68	1	3	

[a] Reaction conditions: Ia (0.1 mole), 30% H_2O_2, $Na_2WO_4 \cdot 2H_2O$ (0.05 mole), 70–80°, 1 hr. [b] See Experimental Section.

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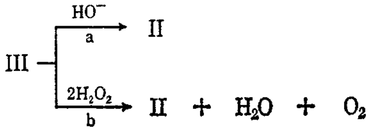
[5] E. J. Corey, *J. Am. Chem. Soc.*, **75**, 1163 (1953).

[6] This is in contradistinction to results obtained by Payne and Williams[2] in the epoxidation of acrylonitrile: equimolar amounts of acrylonitrile and glycidonitrile react with hydrogen peroxide at pH 7.5 to give a yield of only 30% glycidamide in contrast to the 65–70% yields observed with acrylonitrile alone.

with either hydrogen peroxide (Radziszewski reaction[7]) or base. In order to check route a, IIIa was subjected



to the original reaction conditions except for the substitution of water for hydrogen peroxide. No IIa was obtained. Reaction of IIIa with hydrogen peroxide under the same conditions gave IIa in high yield as described above, accompanied by oxygen evolution. These results indicate that III gives II by route b.

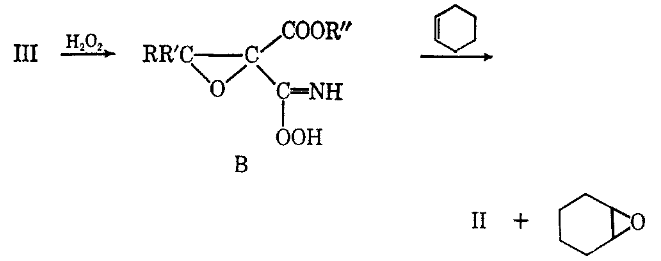
As another approach to II, analogous to the route proposed by Payne,[2,3] epoxidation *via* peroximidic acid (A), was studied (route 3). Reaction of Ia with hydrogen in the presence of sodium tungstate in aqueous ethanolic solution containing cyclohexene gave IIa, IVa, and cyclohexene oxide. The yields of these products are summarized in Table III. No increase of IVa, compared with result for acrylonitrile,[2] indicates that such an approach is excluded for the epoxidation of I under conditions used. Cyclohexene oxide probably arises by reaction of cyclohexene with B as follows.

TABLE III

EPOXIDATION OF Ia IN THE PRESENCE OF CYCLOHEXENE CATALYZED BY Na_2WO_4[a]

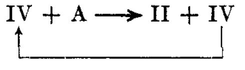
	IVa yield, %[b]	Cyclohexene oxide yield, %[c]
Without cyclohexene[d]	3	
With cyclohexene[d]	4	8

[a] For reaction conditions see the Experimental Section. [b] By amounts of hydrogen absorbed on a mixture of IIa and IVa. [c] By oxirane oxygen content of volatile material. [d] Yield of IIa was 60–65%.



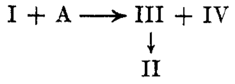
As evidence of such a reaction, IIIa reacted with hydrogen peroxide in the presence of cyclohexene under the original conditions to give cyclohexene oxide (yield, 17%).[8]

The following mechanism involving intermediate A is also considered.



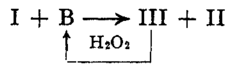
However, this route is unimportant for conversion to II, since IVa was recovered unchanged after treatment with peroxyacetimidic acid[2] prepared from acetonitrile and hydrogen peroxide.

Another possible route to II would be epoxidation of I with A.



The possibility of this was eliminated by the facts that IV does not give II under the original conditions and that this unsaturated amide is obtained only in very low yields under all reaction conditions.

Another possible route appears to be epoxidation of I with intermediate B.



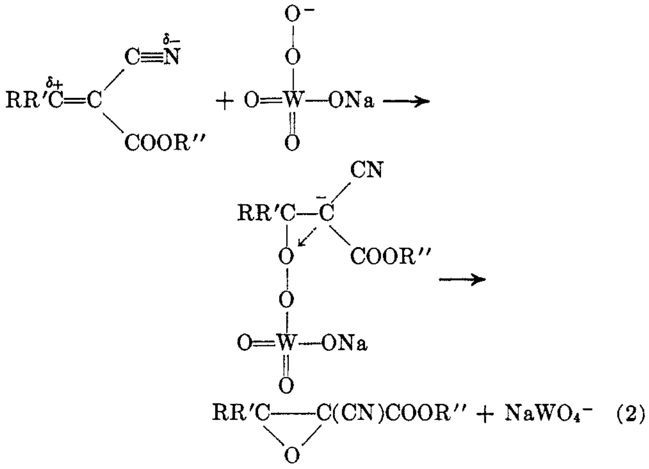
However, this route could not account for the formation of a large amount of oxygen observed during the operation.

Finally, we conclude that route 2 is important in the formation of II from I under alkaline conditions used in the present work.

The reaction is envisioned as proceeding by the addition of a pertungstate anion[9] to the β-carbon atom of I[10] (eq 2). This is followed by the elimination of tungstate anion with the formation of the epoxide, a mechanism analogous to that suggested by Raciszewski[11] for the epoxidation of allyl alcohol with alkaline hydrogen peroxide.

$$Na_2WO_4 + H_2O_2 \longrightarrow Na_2WO_5 + H_2O$$

$$Na_2WO_5 \rightleftharpoons NaWO_5^- + Na^+$$



Further evidence in support of the mechanism was secured by investigating the reaction of β-alkyl-sub-

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[7] B. Radziszewski, *Chem. Ber.*, **17**, 1289 (1884).

[8] Cyclohexene gave no oxide in the absence of cyano ester (see Experimental Section).

(9) Rosenheim[15] studied the oxidation of sodium tungstate with hydrogen peroxide, and isolated sodium pertungstate (Na_2WO_8). Bogdanov studied the similar oxidation and found evidence for existence of various sodium pertungstates (Na_2WO_6, Na_2WO_7, Na_2WO_8) in aqueous solution (C. A. Bogdanov, *Zh. Fiz. Khim.*, **25**, 49 (1951); *Chem. Abstr.*, **46**, 6028 (1951)). Rodriguez obtained Na_2WO_5 which has one active oxygen atom (M. M. Rodriguez, *Anales Fis Y Quim* (Madrid), **40**, 1270 (1944); *Chem. Abstr.*, **43**, 7855 (1949)).

The discussion of the structure of sodium pertungstate is beyond the scope of this paper. The formula Na_2WO_5 was taken from Rodriguez's result and is used in the equations shown.

(10) The epoxidation of an α,β-unsaturated acid with an un-ionized organic per acid is generally very slow (*cf.* D. Swern, *J. Am. Chem. Soc.*, **69**, 1692 (1947)). Similarly, the epoxidation of I with peracetic acid proceeded with difficulty. Therefore, the epoxidation mechanism involving electrophilic attack of an un-ionized sodium pertungstate cannot provide a satisfactory explanation for the behavior of the hydrogen peroxide–sodium tungstate system. It appears that a more satisfactory explanation can be provided by assuming that a pertungstate anion acts as an oxidant. The cyano and carboxyl groups of I sufficiently polarize the ethylenic bond to permit the attack of this anion. The mechanism involving β attack was mentioned by Payne, though not in connection with tungstate.[2]

(11) Z. Raciszewski, *J. Am. Chem. Soc.*, **82**, 1267 (1960).

stituted alkylidenecyanoacetic esters with hydrogen peroxide in the presence of sodium tungstate under standardized conditions (Table IV). As was expected, the presence of a bulky group at the β position of I decreased the yield of the epoxide; in particular, methyl 2-cyano-3-isobutyl-5-methyl-2-hexenoate (If) was recovered unchanged after similar treatment. It is reasonable that the steric hindrance of β substituents largely inhibits the attack of a pertungstate anion.

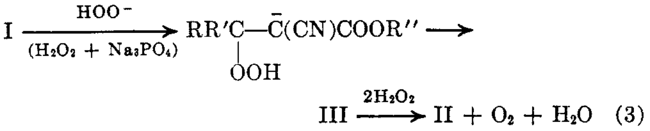
TABLE IV

EPOXIDATION OF β-ALKYL-SUBSTITUTED ALKYLIDENECYANOACETIC METHYL ESTERS IN THE PRESENCE OF SODIUM TUNGSTATE OR TRISODIUM PHOSPHATE[a]

Starting material	Product[b]	Yield, %
Ia[c]	IIa	68 (W)[d]
		65 (P)[e]
Id[f]	IId	38 (W)
		55 (P)
Ie[f]	IIe	9 (W)
		38 (P)
If[g]	IIf	0 (W)
		44 (P)
Ig[g]	IIg	42 (W)

[a] The reactions were carried out under the same conditions given in Table I. [b] See Table X. [c] A. C. Cope, *J. Am. Chem. Soc.*, **59**, 2327 (1937). [d] W: Na_2WO_4–catalyst. [e] P: Na_3PO_4 catalyst. [f] See ref 21. [g] See Experimental Section.

Phosphate Catalysis.—The trisodium phosphate catalyzed reaction of I with hydrogen peroxide was also studied[12] (eq 3). When Ia was treated with 1 molar



$$\mathrm{I} \xrightarrow[(H_2O_2\,+\,Na_3PO_4)]{HOO^-} \mathrm{RR'}\underset{\mathrm{OOH}}{\mathrm{C}}\text{—}\overset{-}{\mathrm{C}}(\mathrm{CN})\mathrm{COOR''} \longrightarrow$$

$$\mathrm{III} \xrightarrow{2H_2O_2} \mathrm{II} + O_2 + H_2O \quad (3)$$

equiv of hydrogen peroxide, epoxy nitrile IIIa was obtained in fair yield along with a low yield of epoxy amide IIa. When excess hydrogen peroxide was used for this reaction, the epoxy amide was obtained in good yield, rather than the epoxy nitrile. The proportion of the epoxy amide to the epoxy nitrile was dependent on the amount of hydrogen peroxide. These results are shown in Table V. The results indicate that epoxy nitrile III is an intermediate for the formation of II from I, resembling the epoxidation with hydrogen peroxide–sodium tungstate described above.[13]

The effects of β-alkyl substituents on I on the yield of II were also examined. Ia, methyl 2-cyano-3,4-dimethyl-2-pentenoate (Id), and methyl 2-cyano-3,4,4-trimethyl-2-pentenoate (Ie) were treated with 30% hydrogen peroxide in the presence of trisodium phosphate. The yields of IIa, methyl 2-carbamoyl-3,4-dimethyl-2,3-epoxypentanoate (IId), and methyl 2-carbamoyl-2,3-epoxy-3,4,4-trimethylpentanoate (IIe) were 65, 55, and 38%, respectively (Table IV).

TABLE V

EPOXIDATION OF Ia WITH VARIOUS AMOUNTS OF HYDROGEN PEROXIDE IN THE PRESENCE OF TRISODIUM PHOSPHATE[a]

H_2O_2/Ia, moles/mole	Yield, %, of product[b] IIa	IIIa	Ia unchanged
0.6	5	49	17
1.0	20	45	6
1.5	36	35	2
2.5	60	7	1
4.0	65	3	

[a] Reaction conditions: Ia (0.1 mole), 30% H_2O_2, $Na_3PO_4 \cdot 12H_2O$ (0.05 mole), 70–80°, 1 hr. [b] See Experimental Section.

TABLE VI

EPOXIDATION OF Ia AND If IN THE PRESENCE OF CYCLOHEXENE CATALYZED BY Na_3PO_4[a]

	From Ia		From If	
	IVa yield, %	Cyclohexene oxide yield, %	IVf yield, %	Cyclohexene oxide yield, %
Without cyclohexene	3		2	
With cyclohexene	3	5	6	13

[a] The reactions were carried out as shown in the Experimental Section, except for the substitution of trisodium phosphate for sodium tungstate.

These results show that increasing the bulk of the β-alkyl substituent results in lower yield of the product. This is in accordance with the results for the reaction using sodium tungstate already described.

The results in Table IV suggest that the inhibition is due to the influence of β-alkyl substituents and nucleophilic agents. The difference between the nucleophilicities of perhydroxyl and pertungstate anions are not important under the conditions given in Table IV for Ia, since Ia gave a nearly identical yield of IIa by the use of these reagents.

As described above, a steric hindrance to the reaction of If with hydrogen peroxide–sodium tungstate was apparent, as evidenced by failure of epoxide formation. When If was treated with 5 molar equiv of hydrogen peroxide in the presence of trisodium phosphate, IIf was obtained in 44% yield along with the starting material (30–40%); the intermediate epoxy nitrile was not obtained. Attempts to detect such an intermediate in various conditions, especially at low temperature, failed. These facts are in marked contrast to the epoxidation of other compounds (Ia–e), which were always contaminated with intermediate III. Therefore, because of a large steric hindrance of the diisobutyl group on the β-carbon atom, it is suggested that the attack of perhydroxyl anion on the electrophilic carbon atom of the nitrile group would be a more plausible first step, although the importance of this attack is negligible with other compounds. That is to say, the formation of IIf from If is considered to proceed *via* a substituted peroxyacrylimidic acid (route 3). To gain further information on the mechanism, cyclohexene, again, was included in the original system. These results are summarized in Table VI. In the case of If, the small increase in unsaturated amide IVf formation was observed, while no increase was observed in Ia. This result supports the above mechanism.[14]

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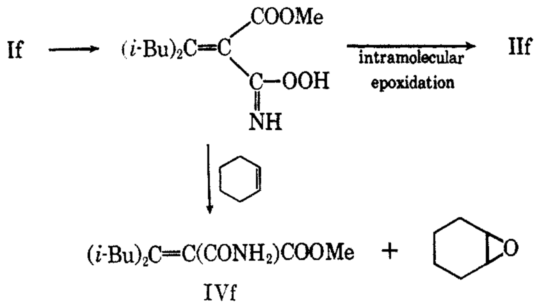
(12) It is known that hydrogen peroxide does not directly oxidize trisodium phosphate to perphosphate (I. W. Mellor, "A Comprehensive Treatise on Inorganic and Theoretical Chemistry," Vol. VIII, Longmans, Green, and Co. Ltd., London, 1928, p 992). Therefore, it is believed that trisodium phosphate acts as base in the epoxidation and perhydroxyl anion acts as an oxidizing agent.

(13) It is conceivable that III yields II with base not involving consumption of hydrogen peroxide. However, when an attempt was made to hydrolyze III in the manner described above, except for the substitution of water for hydrogen peroxide, nearly all of the starting material was recovered.

(14) *Cf.* ref 2. Route 3 might be established more definitively by altering the structure slightly to create *cis–trans* isomerism. Conversion *via* route 3 (assuming this is concerted) should give an epoxy amide of retained geometric configuration. This problem will be discussed in the near future.



Other Catalysis.—Payne[8] obtained IIa′ and IIIa′ in 37 and 30% yields by oxidation of Ia′ with 50% hydrogen under controlled pH conditions using sodium hydroxide. We compared the effects of catalysts by studying the epoxidation of Ia. Ia was treated with 2 molar equiv of hydrogen peroxide in the presence of 0.03 molar equiv of catalyst at 25–30° for 18 hr. These results are shown in Table VII. Sodium tungstate, sodium molybdate, trisodium phosphate, disodium hydrogen phosphate, sodium carbonate, and sodium bicarbonate were effective catalysts in preparation of epoxy nitrile IIIa. The results obtained show roughly that increasing the basicity of the catalyst results in higher yield of the epoxy amide IIa. The use of a larger excess of hydrogen peroxide and the treatment at higher temperature increased the yield of IIa. Acidic catalysts (sodium dihydrogen phosphate, tungstic acid, and molybdic acid) were found to be ineffective, although tungstic and molybdic acids react with hydrogen peroxide to give the corresponding per acids.[15] In this case, higher temperature and excess hydrogen peroxide led to higher yield of epoxy nitrile; no epoxy amide could be detected in the reaction mixture.

Table VII

Epoxidation of Ia in the Presence of Various Catalysts[a]

Catalyst	Yield, %, of product		
	IIa	IIIa	Ia unchanged
	0	23	57
Na_2WO_4	0	84	0
Na_2MoO_4	3	78	0
Na_3PO_4	15	58	0
Na_2HPO_4	1	90	0
NaH_2PO_4	0	30	55
Na_2CO_3	8	65	0
$NaHCO_3$	4	75	0
H_2WO_4	0	20	57
H_2MoO_4	0	20	57

[a] Reaction conditions are given in the Experimental Section.

Also, I was converted into II with sodium pertungstate (Na_2WO_8) produced from sodium tungstate and hydrogen peroxide.

Cyanocinnamates.—In an earlier paper,[4] we showed that ethyl benzylidenecyanoacetate is converted to ethyl 2-carbamoyl-2,3-epoxy-3-phenylpropionate in 46% yield by hydrogen peroxide in the presence of trisodium phosphate. To examine further the synthetic applications of the epoxidation and gain information about the mechanism mentioned above, the action of hydrogen peroxide on ethyl benzylidenecyanoacetate derivatives in the presence of trisodium phosphate was investigated.

The cyanocinnamates Ih–j were subjected to epoxidation under standardized conditions. The results are shown in Table VIII.

Table VIII

Epoxidation of Ih–o with Hydrogen Peroxide in the Presence of Trisodium Phosphate

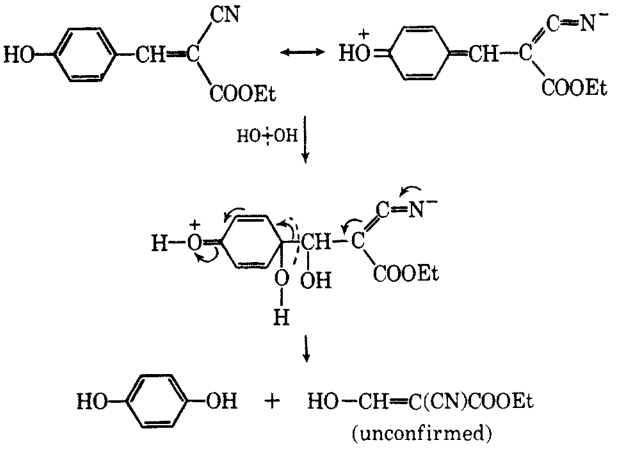
Starting material	Product	Yield, %
Ih[a]	IIh[b]	46
Ii[c]	IIi[d]	65
Ij[c]	IIj[b]	76
Ik[e]	IIk[d]	10
Il[f]	IIl[d]	43
Im[g]	IIm[d]	47
In[h]	IIn[d]	63
Io[i]	IIo[d]	52

[a] W. Baker and A. Lapworth, *J. Chem. Soc.*, **127**, 560 (1925). [b] See ref 4. [c] See ref 18. [d] See Table IX. [e] S. M. Mukherji, R. P. Gandhi, and V. S. Gaind, *J. Indian Chem. Soc.*, **33**, 709 (1956). [f] K. P. Dave and K. S. Nargund, *J. Univ. Bombay*, **7**, 196 (1938); *Chem. Abstr.*, **33**, 3779 (1939). [g] V. Hach and M. Protiva, *Chem. Listy*, **51**, 2099 (1957); *Chem. Abstr.*, **52**, 5309 (1958). [h] J. Zabicky, *J. Chem. Soc.*, **1961**, 683. [i] See ref 25.

Additionally, the effects of polar substituents on the benzene ring on the yield of epoxide were investigated. Ethyl 2-cyano-3-*p*-methoxyphenylacrylate (Ik) was converted into ethyl 2-carbamoyl-2,3-epoxy-3-*p*-methoxyphenylpropionate (IIk) by treatment with 30% hydrogen peroxide in the presence of trisodium phosphate under standardized conditions. The yield was 10%. Ethyl 2-carbamoyl-2,3-epoxy-3-*m*-methoxyphenylpropionate (IIl) and ethyl 2-carbamoyl-2,3-epoxy-3-*o*-methoxyphenylpropionate (IIm) were obtained in 43 and 47% yields from ethyl 2-cyano-*m*-methoxyphenylacrylate (Il) and ethyl 2-cyano-*o*-methoxyphenylacrylate (Im), respectively (Table VIII). Whereas the introduction of the *p*-methoxy group into the benzene ring led to a considerable decrease in the yield, *m*- and *o*-methoxy groups led to no appreciable decrease.

Ethy 12-carbamoyl-2,3-epoxy-3-*p*-nitrophenylpropionate (IIn) and ethyl 2-carbamoyl-2,3-epoxy-3-*o*-nitrophenylpropionate (IIo) were obtained in 63 and 52% yields from ethyl 2-cyano-3-*p*-nitrophenylacrylate (In) and ethyl 2-cyano-3-*o*-nitrophenylacrylate (Io), respectively. Thus the presence of nitro group in the benzene ring leads to an increase in yield of the epoxide (Table VIII).

Ethyl 2-cyano-3-*p*-hydroxyphenylacrylate (Ip) was treated by a procedure identical with that of the



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(15) A. Rosenheim, M. Hakki, and O. Krause, *Z. Anorg. u Allgem. Chem.*, **209**, 175 (1932).

epoxidation described above. This reaction, unlike any other, gave hydroquinone, 50% yield, as the end-product. The course of this reaction may be visualized as shown, although the mechanism is not completely understood.[16]

Examination of the effects of the various substituents in the epoxidation shows that the yields of the epoxides tend to be slightly higher when the β-carbon atom is made more positive. This result supports the mechanism mentioned above.

New epoxy amides II obtained in the present work are summarized in Table IX.

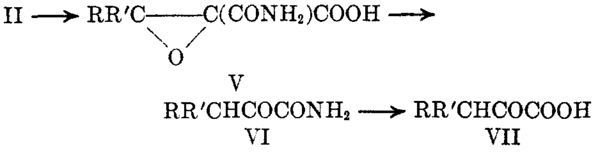
TABLE IX

NEW EPOXY AMIDES II

Compound	Mp, °C	Formula	Calcd, % C	Calcd, % H	Calcd, % N	Found, % C	Found, % H	Found, % N
IIa	134–135	$C_7H_{11}NO_4$	48.55	6.40	8.09	48.34	6.37	8.01
IId	114–116	$C_9H_{15}NO_4$	53.72	7.51	6.96	53.41	7.22	6.71
IIe	114–115	$C_{10}H_{17}NO_4$	55.80	7.96	6.51	55.42	7.53	6.50
IIf	90	$C_{13}H_{23}NO_4$	60.68	9.01	5.44	60.56	8.77	5.23
IIg	95	$C_{13}H_{23}NO_4$	60.68	9.01	5.44	60.13	8.59	5.30
IIi	155–156	$C_{13}H_{17}NO_4$	69.44	5.50	4.50	70.16	5.39	4.51
IIk	161–162	$C_{13}H_{15}NO_5$	58.86	5.70	5.28	58.81	5.64	5.27
IIl	180	$C_{13}H_{15}NO_5$	58.86	5.70	5.28	58.78	5.60	5.22
IIm	157	$C_{13}H_{15}NO_5$	58.86	5.70	5.28	58.80	5.51	5.17
IIn	178–180	$C_{12}H_{12}N_2O_6$	51.43	4.32	9.99	51.23	4.30	9.80
IIo	145	$C_{12}H_{12}N_2O_6$	51.43	4.32	9.99	51.35	4.12	9.76

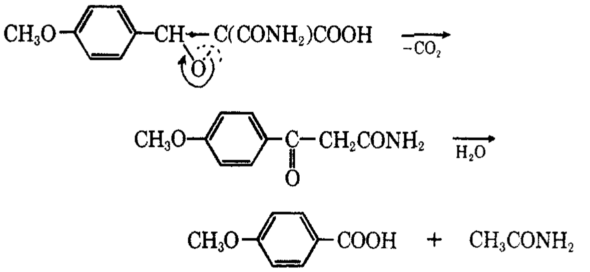
The epoxy compounds II, on treatment with alcoholic potassium hydroxide, gave the potassium salts of the epoxy acids V. Acidification of the salts gave III (R″ = H) without decarboxylation. The yields and melting points of the products obtained are shown in Table X.

The epoxy acids were decarboxylated on heating in an oil bath or on warming with water, giving 2-oxo amides VI (eq 4). The results are shown in Table XI.



$$\text{II} \longrightarrow \underset{\text{V}}{\text{RR'C}\overset{\text{O}}{\text{—}}\text{C(CONH}_2\text{)COOH}} \longrightarrow \underset{\text{VI}}{\text{RR'CHCOCONH}_2} \longrightarrow \underset{\text{VII}}{\text{RR'CHCOCOOH}} \quad (4)$$

2-Carbamoyl-2,3-epoxy-3-*o*-nitrophenylpropionic acid (Vo) gave no 2-oxo amide but gave a resinous product, either by heating at the decomposition point (150°) or by warming it in the aqueous solution. 2-Carbamoyl-2,3-epoxy-3-*p*-methoxyphenylpropionic acid (Vk) gave a resinous product by heating at the decomposition point (124°); it was accompanied by a very small amount of 2-oxo amide (eq 5). On the other hand, by warming in aqueous solution it gave no 2-oxo compound but anisic acid instead in 78% yield; acetamide was a by-product. The mechanism of formation of anisic acid is not certain. The β-oxo compound, from rearrangement of the epoxide, may be an intermediate. It appears possible that anisic acid is formed by hydrolysis of the β-oxo acid.



(5)

The 2-oxo amides VI obtained were hydrolyzed to 2-oxocarboxylic acids VII in good yield. These results are shown in Table XII.

Experimental Section

Epoxidation of Alkylidenecyanoacetic Esters Ia–g.—To a flask equipped with a reflux condenser, thermometer, dropping funnel, and stirrer, I, catalyst, and ethanol were added. To this 30% hydrogen peroxide was added dropwise with stirring. An amount of hydrogen peroxide, the reaction temperature and time and the amount of catalyst are shown in Tables I, II, III and V.

After removal of the solvent, the residue was extracted by the use of chloroform and then the solvent evaporated. The oily residue was shaken with petroleum ether (bp 30–70°) to give colorless crystals. The crystals (II) were contaminated with a very small amount of unsaturated amide IV. In order to determine the amount of IV, the crude crystals were dissolved in ethanol and shaken with hydrogen in the presence of a palladium–carbon catalyst at room temperature under atmosphere pressure. The yield of IV was calculated from the amount of hydrogen absorbed. (Pure II was recovered unchanged under similar conditions.)

The petroleum ether solution obtained above was distilled to give the mixture of epoxy nitrile III and starting material I. The mixture was analyzed by gas chromatography using a Shimadzu Gas Chromatograph, GC-2C. From the areas of individual peaks, the mole % figures were calculated for each product after determining the relative response data by the internal standard method. (The analyses were based on comparisons with authentic samples of the known compounds.)

Isolation of Hydrogenation Compound of IV.—The hydrogenation mixture obtained above was filtered and to the filtrate was added alcoholic potassium hydroxide solution. The resulting potassium salt was collected by filtration. The salt was again dissolved in water and then acidified with dilute hydrochloric acid. The precipitate was collected by filtration and dried. A mixture of the product, water, and benzylamine was heated under reflux for 2 hr. After cooling, the precipitate was filtered off. The filtrate was evaporated to dryness under reduced pressure. The hydrogenation compound of IV was recrystallized from water.

2-Carbamoyl-3-methylpentanoic acid, mp 138–139° dec, (identical melting point and infrared spectra, with a hydrolysis compound of ethyl 2-carbamoyl-3-methylpentanoate[17]) was obtained from ethyl 2-cyano-3-methyl-2-pentenoate (Ib).[18]

Anal. Calcd for $C_7H_{13}NO_3$: C, 52.81; H, 8.23; N, 8.80. Found: C, 52.76; H, 8.12; N, 8.71.

Ethyl 2-carbamoyl-3-methyl-2-pentenoate (IVb) was prepared according to Corey's method;[5] ethyl 1-methylpropylidenemalonate[19] (10.7 g, 0.05 mole) was added dropwise with stirring at 0–10° to 35 g (0.36 mole) of 99% sulfuric acid (prepared from

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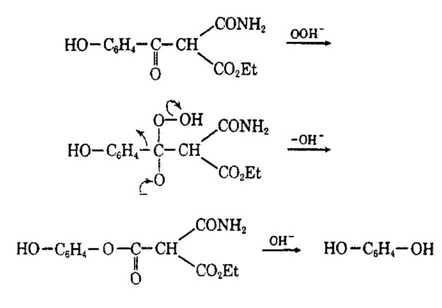
[16] One referee has suggested the following alternative for the formation of hydroquinone.



[17] I. Hori, M. Igarashi, and H. Midorikawa, *J. Org. Chem.*, **26**, 4511 (1961).

[18] A. C. Cope, C. M. Hofmann, C. Wyckoff, and E. Hardenbergh, *J. Am. Chem. Soc.*, **63**, 3452 (1941).

[19] A. C. Cope and E. M. Hancock, *ibid.*, **60**, 2901 (1938).

TABLE X

HYDROLYSIS OF EPOXY ESTERS II

Product	Mp, °C	Yield, %	Formula	Calcd, % C	H	N	Found, % C	H	N
Vh	141 dec	70	$C_{10}H_9NO_4$	57.97	4.38	6.76	58.31	4.48	6.77
Vi	174 dec	88	$C_{16}H_{13}NO_4$	67.84	4.63	4.95	68.09	4.63	4.90
Vk	124 dec	48	$C_{11}H_{11}NO_5$	55.69	4.67	5.91	55.37	4.86	5.80
Vl	145 dec	80	$C_{11}H_{11}NO_5$	55.69	4.67	5.91	55.41	4.61	5.83
Vm	120 dec	78	$C_{11}H_{11}NO_5$	55.69	4.67	5.91	55.72	4.73	5.79
Vn	135 dec	70	$C_{10}H_8N_2O_6$	47.62	3.20	11.11	47.40	3.15	11.08
Vo	150 dec	80	$C_{10}H_8N_2O_6$	47.62	3.20	11.11	47.66	3.11	11.04

TABLE XI

PREPARATION OF 2-OXO AMIDES VII FROM EPOXY ACIDS V

Product	Mp, °C	Yield, %[a]	Formula	Calcd, % C	H	N	Found, % C	H	N
VIh	103–106	70 (A)	$C_9H_9NO_2\cdot{}^1/_2H_2O$	62.78	5.80	8.14	62.69	5.60	8.15
Oxime	147		$C_9H_{10}N_2O_2$			15.72			15.69
VIi	167–168[b]	50 (A)	$C_{15}H_{13}NO_2$	75.30	5.48	5.85	75.23	5.43	5.89
VIl	70	40[c]	$C_{10}H_{11}NO_3$	62.16	5.74	7.25	62.01	5.56	7.03
VIm	85	60 (A), 56 (B)	$C_{10}H_{11}NO_3$	62.16	5.74	7.25	62.31	5.60	6.98
VIn	173–175	72 (B)	$C_9H_8N_2O_4$	51.92	3.87	13.46	51.60	3.75	13.38

[a] Capital letters refer to decarboxylation methods designated by these letters in the Experimental Section. [b] Lit. mp 167–168° [F. F. Blick and J. A. Faust, *J. Am. Chem. Soc.*, **76**, 3156 (1954)]. [c] See Experimental Section.

TABLE XII

PREPARATION OF 2-OXOCARBOXYLIC ACIDS VII FROM 2-OXO AMIDES VI

Product	Mp, °C	Yield, %	Formula	Calcd, % C	H	Found, % C	H
VIIh	154–156[a]	75	$C_9H_8O_3$	65.85	4.91	65.48	4.91
VIIi	115–116[b]	77	$C_{15}H_{12}O_3$	74.99	5.03	74.63	4.81

[a] Lit. mp 156° [M. Bergmann and A. Miekeley, *Ann.*, **458**, 40 (1927)]. [b] Lit. mp 116–117°; ref *b* in Table XI.

20 g of 95% sulfuric acid and 15 g oleum). After storage at room temperature for 17 hr, the solution was poured with stirring into ice. The colorless, oily mixture was extracted with ether and the ether extract was shaken with aqueous sodium hydroxide solution. The aqueous layer was acidified with dilute sulfuric acid. The solution was extracted with chloroform and evaporation of chloroform gave the half-ester which was used without further purification for the following experiment.

To the half ester in 5 ml of benzene was added 2.5 g (0.01 mole) of phosphorus pentachloride and then the solution was concentrated *in vacuo*. The residual liquid was added dropwise with stirring at about −20° to 10 ml of aqueous ammonia and the mixture was allowed to stand for 2 hr at 0°. After filtration, the filtrate was extracted with ether. The ethereal solution was evaporated and the residual oil was let to stand overnight at 0° to crystallize. Recrystallization from chloroform–petroleum ether (bp 30–70°) gave colorless needles, mp 85–87° (yield, 2.5 g).

Anal. Calcd for $C_9H_{15}NO_3$: C, 58.36; H, 8.16; N, 7.56. Found: C, 58.42; H, 8.01; N, 7.37.

IVb and ethyl 2-carbamoyl-3-methyl-2-butenoate (IVa'), mp 107–109° (lit.[5] mp 109–110°), were also obtained from Ib and ethyl 2-cyano-3-methyl-2-butenoate[18] (Ia') respectively by treatment with polyphosphoric acid according to Hori and Midorikawa's method.[20]

To the products obtained above (0.5 g) in ethanol (3 ml) were added 30% hydrogen peroxide (2.5 ml) and sodium tungstate dihydrate (or trisodium phosphate dodecahydrate, 0.2 g). The mixture was kept for 3 hr at 70–80° on a water bath. After removal of ethanol, the crystals were collected by filtration, washed with water, and dried. The starting materials (identified by melting point, mixture melting point, and infrared spectra) were recovered in 84–92% yields.

Ethyl 2-Cyano-2,3-epoxy-3-methylbutanoate (IIIa').—Ia' (15.3 g, 0.1 mole) was added with stirring at room temperature to 9.0 g (0.1 mole) of *t*-butyl hydroperoxide in 60 ml of benzene and 0.2 ml of 40% benzyltrimethylammonium hydroxide (Triton-B). The mixture was allowed to stand at room temperature overnight. The solution was shaken with water. Fractional distillation of the solution gave IIIa': bp 103–104° (10 mm); yield, 50%.

Anal. Calcd for $C_8H_{11}NO_3$: C, 56.79; H, 6.55; N, 8.28. Found: C, 56.34; H, 6.20; N, 8.13.

Infrared spectra gave 4.42 ($C{\equiv}N$), 5.70 ($C{=}O$), 10.59, 11.20 μ (epoxide).

Ethyl 2-Cyano-2,3-epoxy-3-methylnonanoate (IIIc).—The reaction was carried out as in the foregoing method using cumenyl hydroperoxide in place of *t*-butyl hydroperoxide. From Ic, IIIc, bp 153–156° (6 mm), was obtained in 65% yield.

Anal. Calcd for $C_{13}H_{21}NO_3$: C, 65.24; H, 8.85; N, 5.85. Found: C, 65.13; H, 8.76; N, 5.72.

Infrared spectra gave 4.42 ($C{\equiv}N$), 5.70 ($C{=}O$), 10.55, 11.20 μ (epoxide).

Methyl 2-cyano-2,3-epoxy-3-methylbutanoate (IIIa) and methyl 2-cyano-3,4-dimethyl-2,3-epoxypentonate (IIId) were obtained as by-products in the epoxidation of Ia and methyl 2-cyano-3,4-dimethyl-2-pentenoate[21] (Id), respectively (see the epoxidation procedure of I).

Compound IIIa was found to have a boiling point of 110–114° (20 mm).

Anal. Calcd for $C_7H_9NO_3$: C, 54.19; H, 5.85; N, 9.03. Found: C, 53.87; H, 5.54; N, 8.71.

Infrared spectra gave 4.42 ($C{\equiv}N$), 5.70 ($C{=}O$), 10.32, 10.75 μ (epoxide).

Compound IIId was found to have a boiling point of 105–107° (8 mm).

Anal. Calcd for $C_9H_{13}NO_3$: C, 59.00; H, 7.15; N, 7.65. Found: C, 58.81; H, 6.98; N, 7.48.

Infrared spectra gave 4.42 ($C{\equiv}N$), 5.70 ($C{=}O$), 10.78, 11.73 μ (epoxide).

Reaction of III with Hydrogen Peroxide.—Epoxidation of III was carried out by the general procedure. When the reaction was carried out with water in place of hydrogen peroxide, the starting material was recovered in 85–90% yield.

Epoxidation of Ia with Hydrogen Peroxide in the Presence of Cyclohexene.—A mixture of 5 g (0.035 mole) of Ia, 2 g (0.006 mole) of sodium tungstate dihydrate, 4 g (0.055 mole) of cyclohexene, 70 ml of ethanol, and 30 ml (0.26 mole) of 30% hydrogen peroxide was heated on a water bath for 2 hr. The solvent containing cyclohexene oxide was distilled. The oxirane oxygen content of cyclohexene oxide was determined by the method employing dioxane–hydrochloric acid.[22] Titration indicated that 0.23 g of cyclohexene oxide is formed in the reaction.

From the residue from the above distillating operation, IIa and IVa were obtained by the procedure described above.

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(20) I. Hori and H. Midorikawa, unpublished results.

(21) T. Hayashi, M. Igarashi, S. Hayashi, and H. Midorikawa, *Bull. Chem. Soc. Japan*, **38**, 2063 (1965).

(22) G. King, *Nature*, **164**, 706 (1949).

Reaction of cyclohexene with 30% hydrogen peroxide in the presence of sodium tungstate or trisodium phosphate gave no cyclohexene oxide.

Reaction of IIIa with Hydrogen Peroxide in the Presence of Cyclohexene.—To a mixture of IIIa (1.0 g, 0.006 mole), 0.5 g (0.0015 mole) of sodium tungstate dihydrate, 12 ml of ethanol, and 1.0 g (0.013 mole) of cyclohexene was added dropwise 6 ml (0.05 mole) of 30% hydrogen peroxide. The mixture was kept at 70–80° for 2 hr. The solvent containing cyclohexene oxide was distilled. The oxirane oxygen content of the product was determined by titration as described above. The titration indicated that 0.1 g of cyclohexene oxide is produced in the epoxidation. From the residue from the above distillating operation, IIa was obtained in 70% yield.

The experiment was repeated on a large scale. The volatile material was diluted with water and extracted with methylene-chloride. Fractional distillation of the extract gave cyclohexene oxide, bp 125–130° (lit.[23] bp 129–130°).

Anal. Calcd for $C_6H_{10}O$: O (oxirane oxygen), 16.30. Found: O (oxirane oxygen), 15.49.

Reaction of Ia with Hydrogen Peroxide in the Presence of Various Catalysts.—To a mixture of 1.4 g (0.01 mole) of Ia, 3.0 ml of ethanol and 0.003 mole of catalyst (sodium tungstate, trisodium phosphate, disodium hydrogen phosphate, sodium dihydrogen phosphate, sodium carbonate, sodium molybdate, sodium bicarbonate, molybdic acid, and tungstic acid) was added dropwise 2.0 ml (0.017 mole) of 30% hydrogen peroxide with stirring at 25–30°. The mixture was allowed to stand for 18 hr at room temperature (22–30°). Isolation of the product was carried out as described above.

Epoxidation of Ia with Sodium Pertungstate (Na_2WO_8).—The procedure of oxidation of sodium tungstate was that described in the literature.[15] Powdered sodium tungstate was added gradually to 30% hydrogen peroxide: the solution immediately became yellow (pH *ca.* 7.5). To the solution was added a large amount of ethanol. The resulting crystals were collected by filtration and washed with ethanol.

To 1.6 g (0.011 mole) of Ia in aqueous ethanol was added 7 g (0.019 mole) of sodium pertungstate obtained above with stirring at 25–30°. A large evolution of oxygen was observed. The stirring was continued for 20 hr. After removal of the solvent, the mixture was extracted with chloroform. From the chloroform solution, IIa (identified by melting point, mixture melting point with an authentic specimen, and infrared spectra) was obtained: yield, 0.6 g.

Methyl 2-cyano-3-isobutyl-5-methyl-2-hexenoate (If) was prepared according to Cope's method[18] from diisobutyl ketone and methyl cyanoacetate: yield, 60%; bp 138–140° (6 mm).

Anal. Calcd for $C_{13}H_{21}NO_2$: N, 6.27. Found: N, 5.79.

Methyl 3-*n*-butyl-2-cyano-2-heptenoate (Ig) was prepared according to Cope's method from di-*n*-butyl ketone and methyl cyanoacetate: yield, 80%; bp 159–161° (13 mm).

Anal. Calcd for $C_{13}H_{21}NO_2$: N, 6.27. Found: N, 5.86.

Epoxidation of Ethyl Benzylidenecyanoacetate Derivatives Ih–p.—Compound I (0.01 mole), 15 ml (0.13 mole) of 30% hydrogen peroxide, 15 ml of ethanol, and 0.7 g (0.018 mole) of trisodium phosphate dodecahydrate were placed in a round-bottom flask fitted with a reflux condenser, thermometer, and stirrer. The mixture was kept for 2 hr at 70° on a water bath with stirring. After removal of ethanol, the crystals were collected by filtration, washed with water, and dried. A sample was recrystallized from ethanol prior to analysis.

In the case of Ih, after removal of the epoxide by filtration, the filtrate was acidified with dilute hydrochloric acid and extracted with chloroform. The chloroform solution was shaken with aqueous sodium carbonate. This was acidified with dilute hydrochloric acid and the resulting precipitate was collected by filtration. Recrystallization of the product from water gave a 4% yield of benzoic acid, mp 121–122° (identified by mixture melting point with an authentic specimen, mp 123°, and infrared spectra).

The volatile material from the above distillation was indicated to contain benzaldehyde by formation of a 2,4-dinitrophenylhydrazone. This product was isolated by filtration and recrystallized from ethanol to give the 2,4-dinitrophenylhydrazone of benzaldehyde: mp 235–236° (lit.[24] mp 235°); yield, 2%.

Anal. Calcd for $C_{13}H_{10}N_4O_4$: N, 19.58. Found: N, 19.74.

In the case of anisic acid, mp 183° (identified by mixture melting point with an authentic specimen, mp 183°, and infrared spectra), was obtained in 3% yield by the above procedure.

Anal. Calcd for $C_8H_8O_3$: C, 63.15; H, 5.30. Found: C, 62.90; H, 5.37.

From the volatile material, a very small amount of anisaldehyde was obtained as the 2,4-dinitrophenylhydrazone; melting point and mixture melting point with an authentic specimen (lit.[24] mp 250°) was 248–250°.

Hydrolysis of Epoxy Ester II.—To a three-necked flask equipped with a stirrer, dropping funnel, and thermometer was charged a solution of II in ethanol, and ethanol containing an excess of potassium hydroxide was added dropwise under stirring at 20–30°. The mixture was then kept for 1 hr on a water bath. The resulting white precipitate was separated by filtration, washed with ethanol, and dried. The potassium salt was dissolved in water, cooled in an ice bath, and acidified with dilute hydrochloric acid. The resulting precipitate was collected by filtration, washed with water, and dried. A sample was recrystallized from methanol or ethanol prior to analysis.

Decarboxylation of Epoxy Acids V. A.—Compound V was heated with a small amount of water for 3–4 min and allowed to cool to room temperature. The resulting precipitate was collected by filtration. The 2-oxo amide VI obtained gave a dark green color with ferric chloride in ethanol. A sample was recrystallized from water prior to analysis.

B.—Compound V was heated at 170–180° in an oil bath for 2–3 min. The product solidified after cooling. Recrystallization from water afforded colorless plates of 2-oxo amide VI.

Vl gave a resinous product by heating in an oil bath, although the formation of 2-oxo compound was indicated by coloration with ferric chloride. However, this acid gave 2-oxo-3-*m*-methoxyphenylpropionamide in 40% yield by warming in water for 30 min.

Compound Vn was heated in water for 1 hr. The crystalline material isolated by filtration had mp 135° dec; this was identified as starting material by infrared spectra. However, this acid gave 2-oxo-3-*p*-nitrophenylpropionamide (VIn) in 72% yield by procedure B.

Compound Vh gave only a resinous product by heating in water for 1 hr. When it was heated in oil bath at 150°, decomposition proceeded with uncontrollable violence.

Decarboxylation of 2-Carbamoyl-2,3-epoxy-3-*p*-methoxyphenylpropionic Acid (Vk).—The epoxy acid Vk (0.2 g) was heated with a small amount of water for 2 min and allowed to cool to room temperature. The crystalline material isolated by filtration weighed 0.1 g, mp 182–184°; a mixture melting point with anisic acid was 182–184° (also identified by infrared spectra).

Anal. Calcd for $C_8H_8O_3$: C, 63.15; H, 5.30. Found: C, 62.97; H, 5.38.

The filtrate from the isolation of anisic acid above was evaporated to dryness. From the residue, acetamide was obtained (identified by melting point, mixture melting point with an authentic specimen, and infrared spectra).

Hydrolysis of 2-Oxocarbonamide VI.—Compound VI was warmed on a water bath with a slight excess of dilute hydrochloric acid for 30 min and allowed to cool to room temperature. After standing overnight, the resulting precipitate was collected by filtration. An additional amount of the product was obtained from the mother liquor by extraction with ether. Recrystallization from wtater gave colorless plates of 2-oxocarboxylic acid (VII), which gave a dark green color with ferric chloride in ethanol.

Reaction of Ethyl 2-Cyano-3-*p*-hydroxyphenylacrylate[25] (Ip) with 30% Hydrogen Peroxide.—Into a round-bottom flask equipped with thermometer and condenser was charged a solution of 2.0 g (0.01 mole) of Ip in 20 ml of ethanol. To this was added 0.7 g (0.018 mole) of trisodium phosphate dodecahydrate and then 15 ml (0.13 mole) of 30% hydrogen peroxide. The mixture was kept at 70–80° on a water bath for 2 hr. After removal of ethanol, the aqueous solution was extracted with ether. The solvent was evaporated under reduced pressure. The oily residue solidified when it was allowed to stand at room temperature. Recrystallization from benzene gave a 50% yield of hydroquinone, mp 167–171° (identified by mixture melting point with authentic specimen, mp 170–171°, and infrared spectra).

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[23] G. O. Guss and R. Rosenthal, *J. Am. Chem. Soc.*, **77**, 2549 (1955).

[24] E. Funakubo, "Identification of Organic Compounds," Vol. 1, Yokendo, Tokyo, 1954, pp 370–371 (in Japanese).

[25] F. D. Popp, *J. Org. Chem.*, **25**, 646 (1960).

Anal. Calcd for $C_6H_6O_2$: C, 65.44; H, 5.49. Found: C, 65.03; H, 5.43.

Registry No.—If, 13942-37-5; Ig, 14001-84-4; anisic acid, 100-09-4; IIa, 13942-38-6; IId, 13942-39-7; IIe, 13942-40-0; IIf, 13942-41-1; IIg, 13942-42-2; IIi, 13942-43-3; IIk, 13942-44-4; IIl, 13942-45-5; IIm, 13942-46-6; IIn, 13942-47-7; IIo, 13942-48-8; IIIa, 13942-49-9; IIIa′, 13942-50-2; IIIc, 13942-51-3; IIId, 13942-52-4; IVb, 13942-53-5; Vh, 13942-54-6; Vi, 14001-85-5; Vk, 13942-55-7; Vl, 13942-56-8; Vm, 13942-57-9; Vn, 13942-58-0; Vo, 13942-59-1; VIh, 6362-62-5; VIh oxime, 13942-61-5; VIi, 7147-41-3; VIl, 13942-63-7; VIm, 13942-64-8; VIn, 13942-65-9; VIIh, 156-06-9; VIIi, 4834-67-7; hydrogen peroxide, 7722-84-1.

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The Base-Catalyzed Intermolecular Condensation of α,β-Unsaturated Ketones. Condensation of Benzaldehyde with 2-Butanone to Diketones $C_{22}H_{24}O_2$ and $C_{29}H_{28}O_2$

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Two new compounds derived by base-catalyzed (ethanolic sodium ethoxide) condensation of benzaldehyde and 2-butanone are described. Diketone $C_{22}H_{24}O_2$ is obtained slowly in low yield by self-condensation of styryl ethyl ketone and shown to be 3,5-diphenyl-2-methyl-4-propionylcyclohexan-1-one (**7**). Diketone $C_{29}H_{28}O_2$ is 4-(2-benzalpropionyl)-3,5-diphenyl-2-methylcyclohexan-1-one (**12**), obtained readily in 21% yield by condensation of styryl ethyl ketone with 1,5-diphenyl-2-methyl-1,4-pentadien-3-one. Spectral and chemical evidence is presented to support the structural assignments. Reactions of styryl ethyl ketone are compared with results of other workers on condensation reactions of benzaldehyde with 2-butanone and our previous findings on intermolecular self-condensation of other styryl alkyl ketones.

Many investigators have examined the reaction of benzaldehyde with 2-butanone in basic and acidic media. Several products have been reported. This report describes two new products derived from benzaldehyde and 2-butanone—diketones $C_{22}H_{24}O_2$ and $C_{29}H_{28}O_2$.

Products derived from one molecule each of benzaldehyde and 2-butanone include the aldol condensation ketols **1** and **2**[2] and their dehydration products, the corresponding α,β-unsaturated ketones **3** and **4**.[2,3] Acid catalysts favor **4**.[3a,m,4] Ketol formation (**1**, **2**) is favored by mild basic catalysis at low temperature.[2]

$C_6H_5CHOHCH_2COC_2H_5$
1

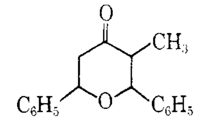
$C_6H_5CHOHCH(CH_3)COCH_3$
2

$C_6H_5CH{=}CHCOC_2H_5$
3

$C_6H_5CH{=}C(CH_3)COCH_3$
4

The distyryl ketone (**5**) has previously been prepared by hydrogen chloride catalyzed condensation of benzaldehyde with 2-butanone or ketone **4**.[3i] Its preparation from benzaldehyde and 2-butanone by base catalysis (aqueous ethanolic sodium hydroxide) is described in the present work.[5] The mono and bis-β-ketols corresponding to **5** have not been prepared. Base

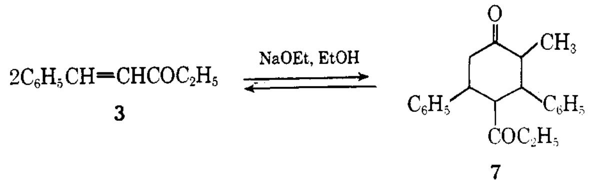
$C_6H_5CH{=}CHCOC(CH_3){=}CHC_6H_5$
5



6

catalysis (aqueous or aqueous ethanolic sodium hydroxide) can produce the tetrahydro-1,4-pyrone **6** from benzaldehyde and 2-butanone,[3a,d,6] or from benzaldehyde and styryl ethyl ketone (**3**).[3d,6]

Condensation products derived from two benzaldehyde and two 2-butanone molecules have not been described previously. Procedures (ethanolic sodium ethoxide or sodium hydroxide, 25°, 1–2 days) which readily effected self-condensation of certain styryl alkyl ketones ($ArCH{=}CHCOCH_2R$ with Ar = phenyl or phenyl with electron-releasing substituents, R = alkyl except CH_3) to cyclic diketone dimers (like **7**)[7] failed with styryl ethyl ketone itself. Diketone **7** forms extremely slowly from **3**; a 1% yield of **7** resulted only after the reaction mixture had been stored at −15° for *ca.* 3 years.



3 **7**

The slow step in formation of **7** is believed to involve Michael cyclization of the anion of the intermediate

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