

TABLE III

Compd	R	Yield, %	Bp (mm) or mp, °C	Formula	Calcd, %		Found, %		
					C	H	C	H	
2-Alkylbenzonitriles									
1	(CH ₃) ₂ CH	69.2	116.0–119.0 (2.5)	C ₁₁ H ₁₃ N	82.97	8.23	82.75	8.02	
2	<i>n</i> -C ₅ H ₁₁	66.0	105.0–106.0 (0.9)	C ₁₅ H ₁₇ N	83.37	9.15	83.28	8.93	
3	C ₆ H ₅ CH ₂	81.0	147.0–148.0 (0.8)	C ₁₅ H ₁₃ N	86.92	6.32	87.21	6.11	
4	<i>p</i> -CH ₃ C ₆ H ₄ CH ₂	21.0	192.0–195.0 (4.5)	C ₁₆ H ₁₅ N	86.84	6.83	86.62	6.71	
Amides									
1a			128.2–129.0 ^a	C ₁₁ H ₁₅ NO	74.54	8.53	74.51	8.52	
2a			115.0–116.0 ^a	C ₁₃ H ₁₉ NO	76.07	9.33	75.87	9.40	
3a			126.0–127.0 ^{a,b}						
4a			138.0–139.0 ^a	C ₁₆ H ₁₇ NO	80.30	7.16	80.15	7.04	

^a Recrystallized from water. ^b Lit. mp 128.0° (see ref 17).

(6.1 g). The Dry Ice condenser was replaced by a water-cooled condenser, the liquid ammonia was displaced by adding 150 ml of ether and heating on a steam bath until the ether began to reflux, and the reaction mixture was then poured onto a water-ice slurry and made acidic to Alkacid test paper by the addition of 6 *N* hydrochloric acid. The phases were separated and the aqueous phase was extracted with several portions of chloroform. The combined ether and chloroform phases were dried over anhydrous sodium sulfate, the solvent was removed at atmospheric pressure, and the residue was distilled *in vacuo* to give *o*-tolunitrile (3.70 g, bp 90–92° at 15 mm), 2-cyanobenzyl phenyl ketone (7.3 g, 66.1%, mp 109.1–109.8° from a 60–70° petroleum ether–benzene mixture), and 3.7 g, of a tarry, high-boiling residue. The nmr and infrared spectra of the product are consistent with the assigned structure. The nmr spectrum determined in CDCl₃ gave the following data: 8.7 (equivalent to 9.0) aromatic protons at $\tau = 1.9$ –2.8 ppm and 2.0 α -methylene protons at $\tau = 5.52$ ppm. The infrared spectrum determined in CHCl₃ showed the following peaks: C≡N at 2242, C=O at 1690, benzene ring at 1609 and 1495, and CH₂ α to a carbonyl group at 1452 cm⁻¹. The ketone gives an oxime, mp 162.4–163.0°, from ethanol–water. Repeating this reaction with a 1:1:1 molar ratio of reactants gave 3.5 g (31.7%) of the ketone, mp 109.0–110.0°. The nmr and infrared spectra of the compounds obtained from the methyl anisate and methyl isobutyrate acylations are consistent with the structural assignment that these compounds are *o*-acylmethylbenzonitriles. From the acylation with ethyl propionate there was obtained 3.6 g (41.6%) of impure 2-cyanobenzyl ethyl ketone, bp 180.0–185.0° at 4.5 mm. Attempts to purify this compound by distillation and column chromatography failed. The nmr spectrum of this impure material determined in CDCl₃ gave the following data: 4.4 (equivalent to

4.0) aromatic protons at $\tau = 2.3$ –3.0 ppm, 2.0 methylene protons α to a benzene ring at $\tau = 6.04$ ppm, 2.1 (equivalent to 2.0) methylene protons corresponding to the CH₂ moiety of the ethyl group at $\tau = 7.41$ ppm, 3.3 (equivalent to 3.0) methyl protons corresponding to the CH₃ moiety of the ethyl group at $\tau = 8.92$ ppm, and a small absorption pattern (four weak lines) of the impurity at $\tau = 7.8$ –8.1 ppm. In addition to the expected bands for a nitrile group, an aromatic ring, a carbonyl group, and a methylene group α to a carbonyl group, the infrared spectrum of this impure cyanoketone showed three bands at 3521, 3339, and 1695 cm⁻¹ which suggest that the impurity may be an amide¹¹ which might have been formed by the hydrolysis of a portion of the ketonitrile.

2. **3-Phenylisocarbostyryl.**—Concentrated sulfuric acid (10.0 ml) was added with cooling to 2-cyanobenzyl phenyl ketone (0.5 g) dissolved in 100 ml of 95% ethanol. After a 3-hr reflux period, the mixture was cooled to room temperature and poured onto ice. Filtration gave 3-phenylisocarbostyryl (0.45 g, 90.0%, mp 198.1–199.0° from ethanol–water; lit.¹³ mp 199.5–200.0°). Its ultraviolet spectrum is identical with that reported in the literature.¹⁶

3. **2-Cyanodibenzyl.**—When reaction 1 was repeated except that the methyl benzoate was replaced by benzyl chloride (0.05 mole, 6.3 g) there were obtained *o*-tolunitrile (3.5 g, bp 90.0–95.0° at 15 mm), 2-cyanodibenzyl (8.4 g, 81.0%, bp 147.0–148.0° at 0.8 mm), and 6.3 g of nondistillable, tarry residue. A sample of the product was heated with concentrated sulfuric acid at 100° for 3 hr and poured onto ice and water to give 2-(2-phenylethyl)benzamide, mp 126.0–127.0°, lit.¹⁷ mp 128.0°.

(16) G. Berti and P. Cori, *Ann. Chim. (Rome)*, **49**, 2112 (1959).

(17) *Cf.* G. Berti, in footnote *b* of Table I.

Ring Cleavage and Oxidation Reactions of Dimethyldimedone

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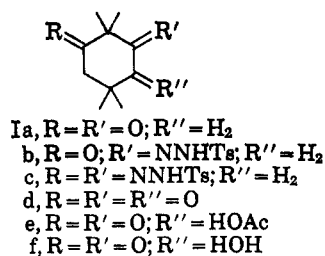
Base treatment of the tosylhydrazone of dimethyldimedone leads to unsaturated ketones. Similar reactions on the monotosylates of its hydride reduction products result in ring scission. Selenium dioxide oxidation of dimethyldimedone yields a trione or tetrone, end products also of successive treatments of the diketone with lead tetraacetate, aqueous acid, and chromic oxide. The stereochemistry of the intermediate ketols and keto acetates is discussed.

The ready availability and polyfunctionality of dimethyldimedone (1a)¹ makes this ketone an ideal starting compound in organochemical synthesis. A study of its chemistry was undertaken in connection with two unrelated problems, syntheses of sesquiterpenes and of the oxidation product of the sex attractant

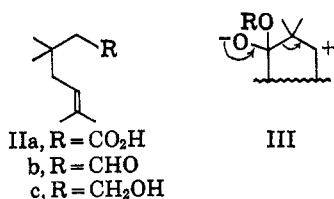
of the virgin female American cockroach, *Periplaneta americana* L.² While only the latter has been completed, a description of both investigations is the subject of the present communication.

(2) J. Meinwald, J. W. Wheeler, A. A. Nimetz, and J. S. Liu, *J. Org. Chem.*, **30**, 1038 (1965), and references cited therein; M. Jacobson and M. Beroza, *Science*, **147**, 748 (1965), and references contained therein; J. R. Chapman, *Tetrahedron Letters*, 113 (1966); B. Singh, *J. Org. Chem.*, **31**, 181 (1966).

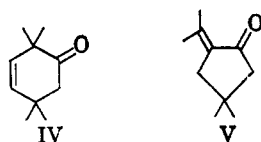
(1) R. D. Desai, *J. Chem. Soc.*, 1079 (1932).



3,3,6-Trimethyl-5-heptenol.—The realm of terpenic natural products abounds with substances containing *gem*-dimethyl groups. The presence of such substituents in Ia recommended its use in terpene synthesis. In the hope of preparing a synthetically useful, acyclic, bifunctional intermediate we investigated ring cleavage reactions of dimethyldimedone-like compounds. While Ia itself had been shown to be cleavable on base treatment,¹ the resultant aliphatic keto acid was a compound in too high a state of oxidation for our purposes. Instead, substances of general structure II were desired and their synthesis was pursued along two reaction paths.

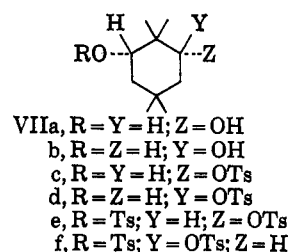


One reaction of interest was the Bamford-Stevens procedure of converting tosylhydrazones into olefins.³ It was assumed that base treatment of dimethyldimedone monotosylhydrazone (Ib) might yield the olefinic acid IIa or its ester by the intervention of the ionic intermediate III. However, exposure of Ib to base led to ketones (IV) cycloartemesia ketone (V),⁴ and, in minor quantity, an unidentified ketone (VI). Formation of IV and V is in accord with previous experience on the Bamford-Stevens reaction.³ 2,3,5,5-Tetramethyl-2-cyclohexenone^{5,6} which also could have been expected to form under the reaction conditions used was absent from the ketone mixture.

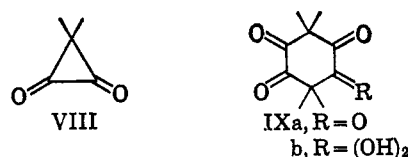


An alternate mode of ring cleavage is based on the fragmentation of 1,3-glycols (VII) or their derivatives. While an attempt of acid-catalyzed cleavage of the glycols has been reported to have failed,⁶ base-induced 1,3 elimination of monotosylates of demethyl analogs of VII has succeeded, although the resultant unsaturated aldehyde had undergone self-condensation.⁷ In view of the recent general success with the latter type

of fragmentation reaction^{7,8} it appeared to be the reaction of choice for the present ring system VII. Hence, both *cis* (VIIa) and *trans* (VIIb) glycols⁹ were converted to their monotosylates VIIc and d, respectively, the latter being treated with potassium *t*-butoxide. Treatment of each ester separately or their mixture in this manner led to the olefinic aldehyde IIb. Lithium aluminum hydride reduction thereof yielded 3,3,6-trimethyl-5-heptenol (IIc). Utilization of this bifunctional compound in terpene synthesis will be the subject of a future communication.



3,3,6,6-Tetramethylcyclohexane-1,2,4,5-tetrone.—Despite serious efforts of structure elucidation of the powerful sex attractant of the American cockroach the full structure of the biologically active compound is still unknown.² Its periodate-permanganate oxidation has been reported to yield propionic acid, acetone, and a neutral substance, mp 55°, whose periodate oxidation afforded dimethylmalonic acid. On the basis of this oxidation result and its mass spectrum the neutral compound was considered to possess the cyclopropanedione structure VIII, although the dimeric structure IXa was not precluded. In view of the inherent chemical interest in a tetrone such as IXa, its possible identity with the degradation product of the cockroach attractant, and its potentially easy preparation from dimethyldimedone (Ia) a study of its synthesis was undertaken.



Selenium dioxide oxidation of dimethyldimedone (Ia) in toluene yielded trione Id. Crystallization from aqueous methanol converted the triketone to a methanol adduct. Exposure to *o*-phenylenediamine produced a quinoxaline (X). When the oxidation of Ia was carried out in acetic acid or for a long time in toluene, the tetrone IXa, mp 233–235°, was produced. Crystallization of the tetraketone from water yielded a monohydrate (IXb), while interaction with *o*-phenylenediamine gave a bisquinoxaline (XI). Periodic acid oxidation of IXa yielded dimethylmalonic acid. The mass spectrum of the tetrone revealed a minor molec-

(3) *Inter alia*: W. R. Bamford and T. S. Stevens, *J. Chem. Soc.*, 4735 (1952); C. H. DePuy and D. H. Froemsdorf, *J. Am. Chem. Soc.*, **82**, 634 (1960).

(4) A. Eschenmoser, H. Schinz, R. Fischer, and J. Cologne, *Helv. Chim. Acta*, **34**, 2329 (1951).

(5) J. Conia, *Bull. Soc. Chim. France*, 690 (1954).

(6) A. W. Allan, R. P. A. Sneeden, and J. M. Wilson, *J. Chem. Soc.*, 2186 (1959).

(7) R. B. Clayton, H. B. Henbest, and M. Smith, *ibid.*, 1982 (1957).

(8) A. Eschenmoser and A. Frey, *Helv. Chim. Acta*, **35**, 1660 (1952); R. B. Clayton and H. B. Henbest, *Chem. Ind. (London)*, 1315 (1953); P. S. Wharton, *J. Org. Chem.*, **26**, 4781 (1961); P. S. Wharton, G. A. Hiegel, and R. V. Coombs, *ibid.*, **28**, 3217 (1963); H. H. Westen, *Helv. Chim. Acta*, **47**, 575 (1964); E. J. Corey, R. B. Mitra, and H. Uda, *J. Am. Chem. Soc.*, **86**, 485 (1964); M. Tanabe and D. F. Crowe, *J. Org. Chem.*, **30**, 2776 (1965); J. A. Marshall and C. J. V. Scanio, *ibid.*, **30**, 3019 (1965); P. S. Wharton and G. A. Hiegel, *ibid.*, **30**, 3254 (1965).

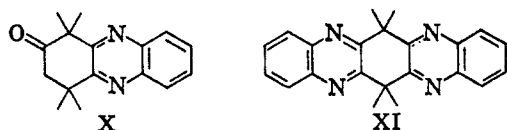
(9) V. P. Hirsjarvi, *Ann. Acad. Sci. Fennicae, Ser. A II*, **23**, 108 (1946); A. W. Allan, R. P. A. Sneeden, and I. Colvin, *J. Chem. Soc.*, 557 (1957); F. W. Grant, R. W. Gleason, and C. H. Bushweller, *J. Org. Chem.*, **30**, 209 (1965).

TABLE I^{a,b}
 PROTON MAGNETIC RESONANCE DATA ON DIMEDONE DERIVATIVES

Compd	C-Methyls	Acetoxymethyls	Methylenes
XVIIIa	1.03 (6)		2.54 (4), 3.33 (2)
XVIIIb	0.82 (3), 1.08 (3), 1.20 (3)		2.34 (4)
Ia	1.00 (6), 1.26 (6)		2.62 (4)
Ie	0.80 (3), 1.17 (3), 1.23 (3), 1.45 (3)	2.22 (3)	2.34, 2.60, 2.94, 3.20 ^c (2)
If	0.66 (3), 1.25 (3), 1.28 (3), 1.43 (3)		2.30, 2.56, 2.84, 3.10 ^c (2)
XIIa	1.00 (6), 1.40 (6)	2.22 (6)	5.54 (2)
XIIb	0.78 (3), 1.21 (3), 1.27 (3), 1.57 (3)	2.25 (6)	5.73 (2)
XIIc	1.00 (6), 1.42 (6)		4.37 (2)
XIId	0.50 (3), 1.35 (3), 1.38 (3), 1.47 (3)		4.53 (2)
XIIIa	1.20 (6), 1.23 (6)	2.22 (6)	5.37 (2)
XIIIb	1.02 (6), 1.37 (6)		4.33 (2)
Id	1.22 (6), 1.37 (6)		2.90 (2)
Id hydrate	0.99 (6), 1.40 (6)		2.78
Id methanolate	0.92 (3), 1.17 (3), 1.28 (3), 1.45 (3)	3.14 ^d (3)	2.12, 2.38, 3.18, 3.44 ^c (2)
IXa	1.42 (12), (CDCl ₃ , 60°)		
	0.92 (12), (benzene, 80°)		
b	1.22 (6), 1.50 (6)		

^a All spectra are run in CDCl₃, unless otherwise stated. ^b Numbers denote chemical shifts in parts per million downfield from tetramethylsilane (δ 0) and those in parentheses number of hydrogens. ^c An AB quartet. ^d Ethereal O-Me.

ular weight peak at m/e 196, a highly intense peak at $M - 28$ corresponding to loss of CO, and fairly intense peaks at $M - 56$ and $M - 71$ indicative of losses of two CO and one methyl, respectively. Only minor peaks, of the intensity of the parent peak, appeared at 97, 98 ($= M/2$), and 99 in sharp contrast to the intense 98 peak reported for the degradation product of the cockroach attractant. The combined data leave no doubt of the structure of the tetrone, while establishing the nonidentity of the tetraketone with the insect attractant oxidation product.



The mass spectrum of the tetrone hydrate (IXb) exhibited a molecular weight peak of medium intensity at m/e 214, all tetrone peaks including medium-sized ones at 98 and 99 and a $M - 28$ peak indicative of CO loss.

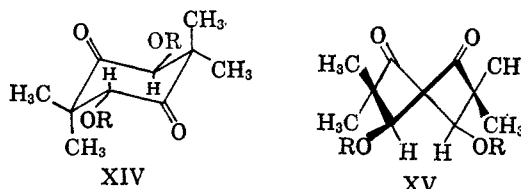
During the time of development of the above oxidation study an investigation of the lead tetraacetate oxidation of dimethyldimedone (Ia) was undertaken. Oxidation in acetic acid yielded a mixture of the monoacetate Ie and two diacetates XIIIa and b. Acid hydrolysis of this mixture led to a mixture of monoalcohol If and three diols. Acetylation of the monohydroxy compound reverted it to the monoacetate Ie, while chromic acid oxidation transformed it into the trione Id. Two of the three diols were shown to be of structure type XII (Chart I) in view of the ready conversion of each into its own diacetate XII. Chromic acid oxidation of each and N-bromosuccinimide oxidation of one of the two diols produced the tetrone IXa. The third diol could be assigned structure XIIIb in view of its conversion into a new diacetate XIIIa on acetic anhydride treatment. In the absence of the fourth possible diketodiols no rigorous assignment of the stereochemistry of XIIIa or b could be made. The simplicity of their pmr spectra (see Table I) indicated a molecular symmetry exhibited only by *trans*-chair (XIV) or *cis*-twist-boat (XV) structures.

CHART I



XIIa, R=R''=H; R'=R''=OAc
 b, R=R''=OAc; R'=R''=H
 c, R=R''=H; R'=R''=OH
 d, R=R''=OH; R'=R''=H

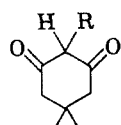
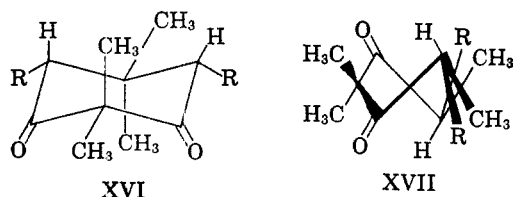
XIIIa, R=Ac
 b, R=H



In the absence of direct chemical data the stereochemical differentiation of the pair of dihydroxydiketones XIIc and d and their acetates had to be based on interpretation of their proton magnetic resonance spectra. Inspection of the pmr C-methyl signals of these and related substances showed them to be of two structure types, those exhibiting four individual three-proton singlets including one at extraordinarily high field and one at low field and those revealing two six-proton singlets (see Table I). The first type represents compounds of chair conformation XVI wherein the axial 5-methyl group, finding itself within the strong shielding cone of both carbonyl groups, would be expected to be shifted strongly upfield, while the equatorial 2-methyl group, lying in the strong deshielding zone of both carbonyl functions, might be expected downfield. The second structure type encompasses compounds of twist-boat conformation XVII which creates a similar environment to each methyl in each of the *gem*-dimethyl pairs. Thus dimedone (XVIIIa)¹⁰ and dimethyldimedone (Ia) appear to possess twist-boat conformations (or chair conformations in rapid equilibrium), while 2-methyldimedone (XVIIIb)¹⁰ and the

(10) While this substance exists in both keto and enol forms in deuteriochloroform solution, the pmr signals of only the keto form have been selected for the present discussion.

acetoxy (Ie) and hydroxy (If) derivatives of dimethyldimedone are held in chair conformations. Furthermore, the acetoxy and hydroxyl groups of Ie and f, respectively, would be expected to be equatorially oriented. These considerations restrict compounds XIIa and c to a *trans* configuration (XVII), while the pair of substances XIIb and d must be of *cis* configuration (XVI).



XVIIIa, R = H
b, R = Me

Experimental Section

Melting points were determined on a Fisher-Johns apparatus and are uncorrected. Infrared spectra were recorded on a Perkin-Elmer spectrophotometer, Infracord Model 137, while ultraviolet spectra were recorded on a Cary 14 spectrophotometer. Proton magnetic resonance spectra were observed on a Varian A-60 spectrometer. Values are given in parts per million relative to tetramethylsilane (TMS) as internal standard (frequency zero). Mass spectra were determined on an Atlas CH-4 spectrometer.

Tosylhydrazones.—A mixture of dimethyldimedone (DMDM, Ia, 8.4 g) and tosylhydrazine (9.3 g) in 100 ml of 1% ethanolic HCl was refluxed for 30 min. Water was added gradually and the solution was cooled. The resultant precipitate was filtered, dried, and warmed at 60–70° in 200 ml of benzene. The insoluble material, 2.5 g, mp ca. 200°, was filtered, while the soluble substance was precipitated by the addition of pentane, yielding 9.2 g of a solid, mp 170–173°. Crystallization of the higher melting material from aqueous ethanol yielded **DMDM bistosylhydrazone** (Ic), mp 223–224°. *Anal.* Calcd for $C_{24}H_{32}N_4O_8S_2$: C, 57.13; H, 6.39; N, 11.11. Found: C, 57.19; H, 6.36; N, 11.25. Crystallization of the low-melting substance from benzene-hexane gave **DMDM tosylhydrazone** (Ib), mp 173–174°. *Anal.* Calcd for $C_{17}H_{24}N_2O_3S$: C, 60.70; H, 7.19; N, 8.33. Found: C, 60.65; H, 7.06; N, 8.23.

Ketones IV–VI.—A mixture of Ib (13 g) in 200 ml of ethylene glycol-sodium ethylene glycolate (from 4.5 g of sodium) was heated at 170–180° until evolution of nitrogen had ceased (ca. 30 min). The cooled solution was poured onto 1300 ml of water and extracted with pentane. The extract was washed with water and with saturated NaCl solution, dried, and evaporated, yielding 4.5 g of a ketone mixture. The water layer was acidified and extracted with ether. The extract yielded no carboxylic acid. The ketone mixture was chromatographed on 200 g of Merck acid-washed alumina. Elution with pentane-ether (50:1) gave IV, V, and thereafter VI. (Ratio 36:7:3 was as determined by integration of glpc peaks. The gas chromatogram was obtained on an Aerograph instrument, Model A90-P, at 120°, using 1% Carbowax Chromasorb W column, 20 ft \times $\frac{3}{8}$ in.) **2,2,5,5-Tetramethyl-3-cyclohexenone** (IV) was distilled, bp 73° (21 mm), n_D^{20} 1.4489. *Anal.* Calcd for $C_{10}H_{16}O$: C, 78.89; H, 10.59. Found: C, 79.16; H, 10.60. Infrared showed $\nu_{max}^{CHCl_3}$ 5.86 μ ; ultraviolet showed λ_{max}^{EtOH} 290 m μ (ϵ 26); pmr (CCl₄) showed two six-proton singlets or δ 1.05, and 1.10 (*gem*-Me₂), two-proton singlet at 2.32 (CH₂), and two-proton near-A₂ multiplet at 5.43 (olefinic H). **2,4-Dinitrophenylhydrazone** had mp 137–139° (ethanol). *Anal.* Calcd for $C_{16}H_{20}N_4O_4$: C, 57.82; H, 6.07; N, 16.86. Found: C, 57.94; H, 6.02; N, 16.98. **3,3-Dimethyl-2-isopropylidene-cyclopentanone** (cycloartemesia ketone, V). Infrared and ultra-

violet spectra were identical with the published data;⁴ pmr (CCl₄) showed a six-proton singlet at δ 1.08 (*gem*-Me₂), two-proton singlet at 2.06 (α -keto CH₂), two-proton broad singlet at 2.37 (CH₂), three-proton broad singlet at 1.78 (olefinic Me), and three-proton triplet at 2.16 ($J = 2$ cps) (olefinic Me). **2,4-Dinitrophenylhydrazone** had mp 221–222° (ethyl acetate). *Anal.* Calcd for $C_{16}H_{20}N_4O_4$: C, 57.82; H, 6.07; N, 16.86. Found: C, 57.75; H, 6.15; N, 16.99. **Ketone VI** was recovered from chromatography fractions in a small amount but was shown to be pure by glpc; mol wt (mass spectrum) 152; infrared showed $\nu_{max}^{CCl_4}$ 5.95 μ ; ultraviolet showed, λ_{max}^{EtOH} 240 m μ (ϵ ca. 1100) (inf), 272 (300) (sh), 301 (200), and 308 (200). **2,4-Dinitrophenylhydrazone** had mp 175–176° (methanol). *Anal.* Calcd for $C_{16}H_{20}N_4O_4$: C, 57.82; H, 6.07; N, 16.86. Found: C, 57.46; H, 5.85; N, 16.61. Synthetic 2,3,5,5-tetramethyl-2-cyclohexenone⁶ was different from VI by retention volume (glpc) and by infrared and ultraviolet spectra. The melting point of its 2,4-dinitrophenylhydrazone, 175–177°,⁶ was depressed upon admixture with the 2,4-DNP of VI.

***cis*-2,2,5,5-Tetramethyl-1,3-cyclohexanediol Tosylate** (VIIc).—To a cooled solution of VIIa⁹ (4.0 g) in 40 ml of pyridine was added a solution of *p*-toluenesulfonyl chloride (5.5 g) in 40 ml of CH₂Cl₂. The mixture was kept for 30 min in an ice bath and then overnight at room temperature. Ice was added and the mixture was stirred for 30 min. More water was added and the water layer was extracted with CH₂Cl₂. The combined extracts were washed with 1 N HCl and then with saturated NaCl solution containing Na₂CO₃. Evaporation of the solvent and crystallization of the residue from pentane-ether gave VIIc, mp 87–90°. *Anal.* Calcd for $C_{17}H_{24}O_4S$: C, 62.56; H, 8.03. Found: C, 63.00; H, 8.09.

***trans*-2,2,5,5-Tetramethyl-1,3-cyclohexanediol tosylate** (VIIId) was prepared from VIIb⁹ by the same procedure as used for VIIc, mp 107–108° (hexane). *Anal.* Calcd for $C_{17}H_{24}O_4S$: C, 62.56; H, 8.03. Found: C, 62.67; H, 7.78.

***cis*-2,2,5,5-Tetramethyl-1,3-cyclohexanediol ditosylate** (VIIe) was obtained from the mother liquors of VIIc and crystallized from pentane-ether, mp 157–158°. *Anal.* Calcd for $C_{24}H_{30}O_6S_2$: C, 60.24; H, 6.32. Found: C, 60.64; H, 6.60.

***trans*-2,2,5,5-Tetramethyl-1,3-cyclohexanediol ditosylate** (VIIIf) was isolated as the less soluble product in the preparation of VIIId, mp 146–147° (benzene-pentane). *Anal.* Calcd for $C_{24}H_{30}O_6S_2$: C, 60.24; H, 6.32. Found: C, 60.56; H, 6.61.

3,3,6-Trimethyl-5-heptenal (IIB).—A solution of VIIc (1.00 g) in dimethyl sulfoxide (DMSO, 5 ml) was introduced dropwise at 20° with stirring into a solution of sodium methylsulfinyl methide (from 72 mg of NaH and 4.5 ml of DMSO) under nitrogen. The mixture was stirred for 30 min at room temperature, cooled, and 15 ml of water was added dropwise. Dilute NaCl solution (60 ml) was added and the solution was extracted with pentane-ether (2:1). The extract was washed with half-saturated and then saturated NaCl solution, dried (Na₂SO₄), and evaporated, yielding 0.46 g of crude IIB. pmr and infrared spectra of the crude material (when compared with the spectra of aldehyde purified by steam distillation) showed it to be of sufficient purity to be used for reduction to IIC (see below); infrared showed $\nu_{max}^{CHCl_3}$ 3.62 (aldehydic CH), 5.83 (CO), 5.95 μ (double bond); pmr (CCl₄) showed a six-proton singlet at δ 1.03 (*gem*-Me₂), two broadened three-proton singlets at 1.60 and 1.73 (olefinic Me), two-proton doublet centered at 2.00 ($J = 8$ cps) (allylic CH₂), two-proton doublet centered at 2.18 ($J = 3$ cps) (α -aldehydo-CH₂), one-proton broad triplet centered at 5.20 ($J = 8$ cps) (olefinic H), and one-proton triplet centered at 9.80 ppm ($J = 3$ cps) (aldehydic H). **2,4-Dinitrophenylhydrazone** had mp 93–94° (ethanol). *Anal.* Calcd for $C_{16}H_{22}N_4O_4$: C, 57.47; H, 6.63; N, 16.76. Found: C, 57.38; H, 6.62; N, 16.71.

The aldehyde IIB could also be obtained by the same procedure from VIIId or from mixtures of VIIc and d. When the ditosylates VIIe or f, accompanying the monotosylates VIIc or d, were not completely eliminated before reaction, the aldehyde obtained contained the ditosylates. They could be removed by leaving the crude aldehyde in a small amount of pentane overnight at 0° and filtering the precipitate.

The procedure used for preparation of larger amounts of the aldehyde IIB consisted of treating the crude reduction product of Ia with TsCl and submitting the crude tosylate mixture to the elimination reaction. Thus, to a warm solution (70°) of mixed tosylates (VIIc-f, 15 g) in benzene (150 ml) was added in one portion 75 ml of a saturated *t*-BuOK solution in *t*-butyl alcohol with shaking and the mixture was kept at 70° for 5 min. It then

was poured onto 600 ml of water and extracted with 300 ml of pentane. The extract was washed with water, with 5% aqueous HCl, again with water, and with saturated NaCl solution containing Na_2CO_3 . Evaporation of the solvent yielded 7.5 g of IIb, containing some ditosylates which were removed as described above.

3,3,6-Trimethyl-5-heptenol (IIc).—A solution of IIb in 50 ml of ether was introduced dropwise into a suspension of LiAlH_4 (0.74 g) in 150 ml of ether, and refluxed for 90 min. After cooling in an ice bath, the mixture was decomposed with saturated Na_2SO_4 solution in the usual manner. The clear ether solution was washed with a saturated NaCl solution, dried (Na_2SO_4), and evaporated, yielding 4.6 g of IIc, infrared spectrum, $\nu_{\text{max}}^{\text{C}_2\text{H}_5\text{CN}}$ 3.00 μ (OH) and 5.98 μ (double bond), no carbonyl absorption; pmr (CCl_4) showed a six-proton singlet at δ 0.85 (*gem*-Me₂), multiplet from 1.25 to 1.90 (two CH₂), broad singlets at 1.60 and 1.73 (olefinic Me), two-proton triplet centered at 3.60 ($J = 7.5$ cps) (α -hydroxy-CH₂), and one-proton broad triplet centered at 5.18 ($J = 7$ cps) (olefinic H).

p-Phenylazobenzoate had mp 77–78° (pentane). *Anal.* Calcd for $\text{C}_{23}\text{H}_{25}\text{N}_2\text{O}_2$: C, 75.79; H, 7.74; N, 7.69. Found: C, 75.98; H, 7.77; N, 7.73.

trans- and *cis*-Diacetoxy-DMDM (XIIa and b).—A solution of DMDM (Ia, 1 mole) in acetic acid (75 ml/7 g of Ia) containing $\text{Pb}(\text{OAc})_4$ (2.2 moles) was refluxed for 30 min. After cooling the solution was poured into a large beaker containing saturated NaCl solution and most of the acetic acid was neutralized with solid Na_2CO_3 . The mixture was extracted with ether and the extract was washed with a saturated NaCl solution containing Na_2CO_3 and dried (Na_2SO_4). Evaporation of solvent gave a mixture of compounds, crystallization of which from ether separated pure XIIa in ca. 40% yield. The remaining mixture was chromatographed on Florisil (100 g/1 g of the mixture). Elution with increasing proportions of ether in pentane eluted Ia, e, XIIa, and b. *trans*-2,2,5,5-Tetramethylcyclohexa-4,6-diol-1,3-dione diacetate (XIIa) was crystallized twice from ether, mp 143–144°. *Anal.* Calcd for $\text{C}_{14}\text{H}_{20}\text{O}_6$: C, 59.14; H, 7.09. Found: C, 59.49; H, 7.19. Infrared showed, $\nu_{\text{max}}^{\text{KBr}}$ 5.72, 5.77 (sh), and 5.87 μ (CO); pmr spectrum, see Table I. *cis*-2,2,5,5-Tetramethylcyclohexa-4,6-diol-1,3-dione diacetate (XIIb) was crystallized from pentane, mp 142–143°. *Anal.* Calcd for $\text{C}_{14}\text{H}_{20}\text{O}_6$: C, 59.14; H, 7.09. Found: C, 59.25; H, 7.06. Infrared showed $\nu_{\text{max}}^{\text{KBr}}$ 5.72, 5.76 (sh), and 5.85 μ (CO); pmr spectrum, see Table I. 2,2,5,5-Tetramethylcyclohexa-4-ol-1,3-dione acetate (Ie) was crystallized twice from pentane, mp 116–117°. *Anal.* Calcd for $\text{C}_{12}\text{H}_{18}\text{O}_4$: C, 63.70; H, 8.02. Found: C, 63.83; H, 7.86.

trans- and *cis*-Dihydroxy-DMDM (XIIc and d).—A mixture of XIIa (4.0 g) in 50 ml of methanol-20% aqueous H_2SO_4 (1:1) was refluxed for 30 min. Most of the methanol was evaporated under vacuum and the remaining solution was poured onto 200 ml of saturated NaCl solution and extracted 10–12 times with 25-ml portions of ether. The combined extracts were dried on K_2CO_3 and evaporated, yielding 3.0 g of crude product. Trituration with pentane and crystallization from benzene gave *trans*-2,2,5,5-tetramethylcyclohexa-4,6-diol-1,3-dione (XIIc) in ca. 70% yield, mp 127–128°. *Anal.* Calcd for $\text{C}_{10}\text{H}_{16}\text{O}_4$: C, 59.98; H, 8.05. Found: C, 60.11; H, 7.98. Infrared showed $\nu_{\text{max}}^{\text{KBr}}$ 2.98 (OH), 5.79, and 5.90 μ (CO); ultraviolet showed $\lambda_{\text{max}}^{\text{CH}_2\text{CN}}$ 282 m μ (ϵ 50); pmr spectrum, see Table I. Treatment of XIIc with acetic anhydride in pyridine overnight at room temperature yielded pure XIIa (by pmr). Hydrolysis of XIIb under the above conditions followed by crystallization from benzene-pentane yielded a mixture of XIIc and d (ca. 1:1 by pmr measurement) which was chromatographed on a 100-fold quantity of Florisil. Elution with pentane-ether (20:1) gave XIIc then d. *cis*-3,3,5,5-Tetramethylcyclohexa-4,6-diol-1,3-dione (XIIId) had mp 172–174° (benzene-hexane). *Anal.* Calcd for $\text{C}_{10}\text{H}_{16}\text{O}_4$: C, 59.98; H, 8.05. Found: C, 60.11; H, 8.02. Infrared showed $\nu_{\text{max}}^{\text{KBr}}$ 2.90, 2.99 (OH), 5.80, and 5.90 μ (CO); ultraviolet showed $\lambda_{\text{max}}^{\text{CH}_2\text{CN}}$ 277 m μ (ϵ 130); pmr spectrum, see Table I. Treatment of XIIId with acetic anhydride in pyridine overnight at room temperature yielded pure XIIb (by pmr).

2,2,5,5-Tetramethylcyclohexa-4-ol-1,3-dione (If), 2,2,5,5-Tetramethylcyclohexa-3,6-diol-1,4-dione (XIIIb) and Diacetate (XIIIa).—Hydrolysis of a mixture of XIIa, b, and Ie under the above conditions yielded a mixture of hydroxy compounds, which were more easily separated by chromatography than the parent acetates. To this mixture was added also residues and mother liquors from previous hydrolyses and the combined mixture was

chromatographed on Florisil (100 g/1 g of mixture). Elution with pentane-ether (20:1–10:1) yielded four compounds, the last two being XIIc and d already described. The first compound to be eluted from the column was 2,2,5,5-tetramethylcyclohexa-3,6-diol-1,4-dione (XIIIb). It was crystallized from hexane and then from benzene, mp 218–219°. *Anal.* Calcd for $\text{C}_{10}\text{H}_{16}\text{O}_4$: C, 59.98; H, 8.05. Found: C, 60.30; H, 7.98. Infrared showed $\nu_{\text{max}}^{\text{KBr}}$ 2.93 (OH) and 5.88 μ (CO); ultraviolet showed $\lambda_{\text{max}}^{\text{CH}_2\text{CN}}$ 278 m μ (ϵ 210); pmr spectrum, see Table I. Acetylation of XIIIb with acetic anhydride in pyridine gave 2,2,5,5-tetramethylcyclohexa-3,6-diol-1,4-dione diacetate (XIIIa), mp ca. 155°, then 170–173° (hexane). *Anal.* Calcd for $\text{C}_{14}\text{H}_{20}\text{O}_6$: C, 59.14; H, 7.09. Found: C, 59.29; H, 6.84. Infrared showed $\nu_{\text{max}}^{\text{KBr}}$ 5.72 and 5.87 μ (CO); pmr spectrum, see Table I. The second compound to be eluted was 2,2,5,5-tetramethylcyclohexa-4-ol-1,3-dione (If), mp 118–119° (hexane). *Anal.* Calcd for $\text{C}_{10}\text{H}_{16}\text{O}_3$: C, 65.19; H, 8.75. Found: C, 65.35; H, 8.88. Infrared showed $\nu_{\text{max}}^{\text{KBr}}$ 5.74, 5.81, and 5.91 μ (CO); pmr spectrum, see Table I. Acetylation with acetic anhydride in pyridine gave Ie.

Trione Id. A. From DMDM.—A mixture of DMDM (Ia, 6 g) and SeO_2 (10 g) in 70 ml of toluene was refluxed for 24 hr. Selenium was filtered and ether was added. The solution was washed several times with saturated NaCl solution, dried (Na_2SO_4), and evaporated. The solid was dissolved in a minimum amount of benzene and chromatographed on 150 g of Merck acid-washed alumina. Elution with pentane-ether (4:1) yielded 3.5 g (53%) of crystalline 2,2,5,5-tetramethyl-1,3,4-cyclohexanetrione (Id), mp 128–129° (light yellow prisms from CCl_4). *Anal.* Calcd for $\text{C}_{10}\text{H}_{14}\text{O}_3$: C, 65.91; H, 7.74. Found: C, 65.77; H, 7.66. In the presence of water the trione Id gave an unstable hydrate and extracts from water were colorless. Sometimes upon evaporation of somewhat wet solutions or of chromatography fractions an almost colorless hydrate was obtained, which melted at ca. 110° with loss of water and then resolidified melting normally at ca. 130°. Upon evaporation of a benzene solution or by crystallization from CCl_4 or pentane, however, the yellow trione was obtained.

B. From If.—To a solution of If (0.59 g) in 20 ml of acetone was added an equivalent amount of Jones reagent (CrO_3 in H_2O - H_2SO_4 , 20% excess above 0.67 mole of CrO_3 was used). After 5 min at room temperature water and saturated NaCl solution were added and the solution was extracted several times with ether. The extract was washed with saturated NaCl solution and dried (Na_2SO_4). Evaporation of solvent yielded 0.58 g of a solid residue which gave the pure trione Id upon crystallization from CCl_4 ; infrared showed $\nu_{\text{max}}^{\text{KBr}}$ large CO absorption at 5.75–5.90 μ ; ultraviolet showed $\lambda_{\text{max}}^{\text{CH}_2\text{CN}}$ 255 m μ (ϵ 57) (sh) and 407 m μ (ϵ 18); pmr spectra of freshly prepared solutions in dry solvents showed only the trione bands (see Table I). In the presence of water the bands of the hydrate appeared also (see Table I). The relative intensities of the trione and trione hydrate bands could be varied by variation of the temperature of the sample.

Quinoxaline X.—A mixture of Id (364 mg) and *o*-phenylenediamine (216 mg) in 5 ml of AcOH was refluxed for 30 min. After cooling water was added and the precipitated crystals (450 mg) were filtered, washed with water, and crystallized twice from ethanol, mp 135–136°. *Anal.* Calcd for $\text{C}_{15}\text{H}_{13}\text{N}_2\text{O}$: C, 75.56; H, 7.13; N, 11.02. Found: C, 75.43; H, 7.22; N, 10.95. Pmr (CDCl_3) showed two six-proton singlets at δ 1.45 and 1.60 (*gem*-Me₂), two-proton singlet at 2.86 (CH₂), and a four-proton symmetrical multiplet centered at 7.88 (aromatic H).

Trione Methanolate.—By crystallization of the trione Id from methanol, heavy, colorless prisms were obtained. Small yellow crystals of the trione appeared on their surface upon long standing. The same colorless trione methanolate was obtained by crystallization of the trione from aqueous methanol, mp 65–66°. *Anal.* Calcd for $\text{C}_{11}\text{H}_{18}\text{O}_4$: C, 61.66; H, 8.47. Found: C, 61.78; H, 8.32. Infrared showed $\nu_{\text{max}}^{\text{KBr}}$ 3.01 (OH), 5.83 (OH), and 5.93 μ (CO); ultraviolet showed $\lambda_{\text{max}}^{\text{CH}_2\text{CN}}$ 295 m μ (ϵ 60); pmr spectrum, see Table.

Tetrone IXa. A. From DMDM by SeO_2 Oxidation in AcOH.—A mixture of DMDM (Ia, 5 g) and SeO_2 (10 g) in 50 ml of acetic acid was refluxed for 30 min. Benzene (200 ml) was added to the cooled and filtered solution and precipitated excess SeO_2 was removed by filtration. Most of the benzene was removed under vacuum and the acid solution poured onto 300 ml of water-saturated NaCl solution (1:1) and then extracted five times with ether. The ether extract was washed with a saturated NaCl

solution containing Na_2CO_3 and dried (Na_2SO_4). The residue obtained by evaporation of solvent was dissolved in ether and filtered through 20 g of Merck acid-washed alumina. Upon evaporation and trituration of the residue with benzene 2.5 g of a yellow solid were obtained. Crystallization from benzene gave 3,3,6,6-tetramethyl-1,2,4,5-cyclohexanetetrone (IXa), mp 233–235° (very rapid sublimation above 200°). *Anal.* Calcd for $\text{C}_{10}\text{H}_{12}\text{O}_4$: C, 61.21; H, 6.17. Found: C, 61.23; H, 6.00.

B. From DMDM by SeO_2 Oxidation in Toluene.—A mixture of DMDM (Ia, 5 g) and SeO_2 (15 g) in 70 ml of toluene was refluxed for 60 hr. After cooling the precipitated material was filtered and the solvent was evaporated. The partly solid residue was taken up in benzene and the insoluble, crystalline material was filtered and purified as above yielding the pure tetrone IXa. Chromatography of the benzene-soluble fraction yielded a small amount of the trione Id.

C. From *trans*-Dihydroxy-DMDM (XIId) by CrO_3 Oxidation.—To a solution of XIId (0.30 g) in 10 ml of acetone at 0° was added 2.2 equiv of Jones reagent. After 5 min at room temperature water-saturated NaCl solution (1:1) was added. After extraction with ether, washing of the extract with saturated NaCl solution, drying, and evaporation of the solvent, 260 mg of a solid yellow residue was obtained. Crystallization from CCl_4 yielded the pure tetrone IXa.

D. From a Mixture of *cis*- and *trans*-Dihydroxy-DMDM (XIId and d) by CrO_3 Oxidation.—A high yield of the tetrone IXa was obtained when oxidation with CrO_3 was carried out as above on a mixture of XIId and d, containing mainly the *cis* isomer XIId (as evidenced by the pmr spectrum of the mixture).

E. From *trans*-Dihydroxy-DMDM (XIId) by Oxidation with *N*-Bromosuccinimide (NBS).—A mixture of XIId (200 mg) and NBS (400 mg) in 10 ml of CCl_4 was brought to refluxing with an electric bulb. Reaction occurred rapidly with liberation of HBr and some bromine. Bromine disappeared on continued refluxing. After *ca.* 1 hr the mixture was cooled and the succinimide was filtered. The solvent was evaporated, yielding a yellow, oily residue from which crystals separated on standing. These were collected and crystallized from benzene, yielding the pure tetrone IXa.

The tetrone readily formed a hydrate in the presence of water (see below). When the infrared spectrum was taken in KBr, the spectrum of the hydrate was obtained. The physical characteristics of the tetrone IXa are: infrared spectrum, $\nu_{\text{max}}^{\text{KBr}}$ large CO absorption 5.74–5.90 μ , no OH absorption; ultraviolet spectrum, $\lambda_{\text{max}}^{\text{CH}_3\text{CN}}$ 258 m μ (ϵ 360), *ca.* 287 (sh) (180), and 410 (46); $\lambda_{\text{max}}^{\text{CHCl}_3}$ 256 m μ (ϵ 185) (sh) and 407 m μ (ϵ 42); pmr spectra may show the two *gem*-dimethyl singlets of the hydrate (see

Table I) besides the tetrone single peak. A good spectrum of the tetrone is obtained in CDCl_3 at 60° or in benzene at 80° (see Table I) showing only very low peaks of the hydrate.

Bisquinoxaline XI.—A mixture of IXa (21 mg) and *o*-phenylenediamine (25 mg) in 3 ml of acetic acid was refluxed for a few minutes. Water was added to the cooled solution and the precipitated solid was filtered, washed with water, and crystallized from ethanol, mp 267–268°. *Anal.* Calcd for $\text{C}_{22}\text{H}_{20}\text{N}_4$: C, 77.62; H, 5.92; N, 16.46. Found: C, 77.70; H, 5.92; N, 16.22. Pmr (CDCl_3) showed a 12-proton singlet at δ 2.99 (*gem*- Me_2) and an eight-proton symmetrical multiplet centered at 7.90 (aromatic H).

Tetrone Hydrate (IXb).—By crystallization of the tetrone IXa from water heavy, pale yellow prisms of the tetrone hydrate IXb were obtained, mp *ca.* 170° (when put on the melting block at that temperature) with loss of water and resolidification followed by rapid sublimation of the tetrone. By slow warming from lower temperatures, there was no melting but continuous change into the tetrone. *Anal.* Calcd for $\text{C}_{10}\text{H}_{14}\text{O}_5$: C, 56.07; H, 6.59. Found: C, 56.11; H, 6.71. Infrared showed $\nu_{\text{max}}^{\text{KBr}}$ 3.02 (OH) and 5.70 μ (CO); $\nu_{\text{max}}^{\text{Nujol}}$ 3.05 (OH) and 5.71 μ (CO); ultraviolet showed $\lambda_{\text{max}}^{\text{CH}_3\text{CN}}$ 262 m μ (ϵ 260), 410 m μ (ϵ 30); pmr showed that the tetrone hydrate (IXb) had a low solubility in CDCl_3 at room temperature, but the tetrone singlet at δ 1.42 was not observed in the spectrum of the hydrate (see Table I). Upon warming to 60°, the tetrone singlet appeared together with the two hydrate singlets, and grew slowly with time.

Oxidation of the Tetrone (IXa).—To a solution of IXa (0.3 g) in 20 ml of water was added a solution of periodic acid (2.5 g) in a few milliliters of water. After standing for 1 hr at room temperature ethylene glycol was added to destroy the excess oxidizing agent and the solution was extracted with ether. The extract was washed with sodium thiosulfate solution and with saturated NaCl solution, dried, and evaporated. Crystallization of the residue from ether-pentane gave dimethylmalonic acid, mp 185–190°. Trituration with boiling chloroform raised the melting point to 203–204°. Esterification of the acid with diazomethane yielded oily methyl dimethylmalonate, the pmr spectrum of which showed only two singlets at δ 1.45 and 3.73 (ratio 1:1).

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The Chemistry of Allene. II. The Kinetics of Free-Radical Addition of Hydrogen Bromide

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The kinetics of the free-radical addition of HBr to allene at -78° has been investigated and a mechanism for the reaction is proposed. Bromine atom adds both to the terminal and the central carbon of allene with a ratio of the corresponding rate constants $k_1/k_2 = 2.0$, *i.e.*, the addition occurs statistically. Reversibility of Br· addition at C_1 and nonreversibility of addition at C_2 of allene accounts for the effects of the reaction conditions on the ratio of terminal and central adducts, $[\text{T}]/[\text{C}]$. At constant temperature, $[\text{T}]/[\text{C}]$ is independent of allene concentration, but is uniquely dependent on the HBr concentration.

The factors influencing the product distribution in free-radical addition to allene are not well understood at present. The point of initial attack of free radicals, *i.e.*, terminal *vs.* center, has also been controversial. The free-radical addition of HBr to allene in the gas phase at room temperature or above gave 2-bromopropene as the only monoadduct.^{1,2} The exclusive

formation of 2-bromopropene was explained in terms of Br· attacking the terminal carbon then migrating to the center carbon to give a resonance-stabilized radical, followed by hydrogen abstraction to yield the central isomer.¹ The addition of HBr in the liquid phase at room temperature, however, gave small amounts of 3-bromopropene;^{2,3} its proportion increased at lower reaction temperatures and at high

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