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REACTIONS OF THE 1-HALO-7-(2-HYDROXYETHOXY)CYCLOHEPTENES AND THE 3-HALO-4-(2-HYDROXYETHOXY)BICYCLO[3.2.1]OCT-2-ENES WITH POTASSIUM *t*-BUTOXIDE†

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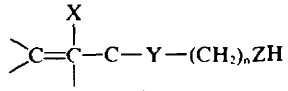
Abstract—Reactions of 1 - bromo - 7 - (2 - hydroxyethoxy)cycloheptene **2** and its chloro analogue **3** with potassium *t*-butoxide in dimethyl sulphoxide or tetrahydrofuran gave cycloheptatriene and *cis* - 8,11 - dioxabicyclo[5.4.0]undec - 2 - ene **18** as the major products together with small amounts of the *trans*-isomer **17**, 8,11 - dioxabicyclo[5.4.0]undec - 1(7) - ene **14**, 8,11 - dioxabicyclo[5.4.0] - undec - 1 - ene **19**, cyclohept - 2 - enone ethylene ketal **15**, cyclohept - 3 - enone ethylene ketal **16**, and 1- and 2 - *t* - butoxycyclohepta - 1,3 - diene **20**. Similar reactions of 3 - bromo - and 3 - chloro - 4 - (2 - hydroxyethoxy)bicyclo[3.2.1]oct - 2 - ene **4** and **5** gave 4,7 - dioxatricyclo[7.2.1.$0^{3,8}$]dodeca - 2 - ene **26** as the major product together with small amounts of 3,6 - dioxatricyclo[7.2.1.$0^{2,7}$]dodeca - 2(7) - ene **27** and bicyclo[3.2.1]oct - 3 - ene - 2 - one ethylene ketal **28**. Mechanisms for these transformations are discussed.

As a continuation of our efforts to determine the scope and limitations of base-induced cyclization reactions of haloallyl compounds that can be represented generally by **1**,[1] we prepared the 1 - halo - 7 - (2 - hydroxyethoxy)cycloheptenes **2** and **3**, and the 3 - halo - 4 - (2 - hydroxyethoxy)bicyclo[3.2.1]oct - 2 - enes **4** and **5**, and studied their reactions with potassium *t*-butoxide (*t*-BuOK).



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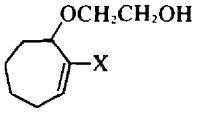

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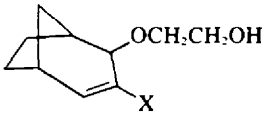
3: X = Cl



4: X = Br
5: X = Cl

The major products from the reactions of 1 - bromo - and 1 - chloro - 6 - (2 - hydroxyethoxy) - cyclohexene (**6** and **7**) with *t*-BuOK in dimethylsulphoxide (DMSO) are cyclohex - 2 - enone ethylene ketal **8** and *cis* - 2,5 - dioxabicyclo[4.4.0]dec - 7 - ene **9**, which are obtained in ratios of 1:1 and 2:1, respectively.[2] The combined yield of **8** and **9** from these reactions exceeds 70%. In tetrahydrofuran (THF), **6** and *t*-BuOK gave **8** and **9** in yields of 0.6% and 3.5% together with a 1.5% yield of 2,5 - dioxabicyclo[4.4.0] - dec - 6 - ene **10** and a 69% yield of benzene. Prototropic rearrangement of **6** or **7** to the corresponding *cis*- and *trans* - 3 - halo - 4 - (2 - hydroxyethoxy)cyclohexenes (**11** and **12**) (Scheme 1), was proposed to account for the formation of **8**, **9**, and benzene. Formation of the small amount of **10** was accounted for as occurring via the cyclohexyne intermediate **13**.

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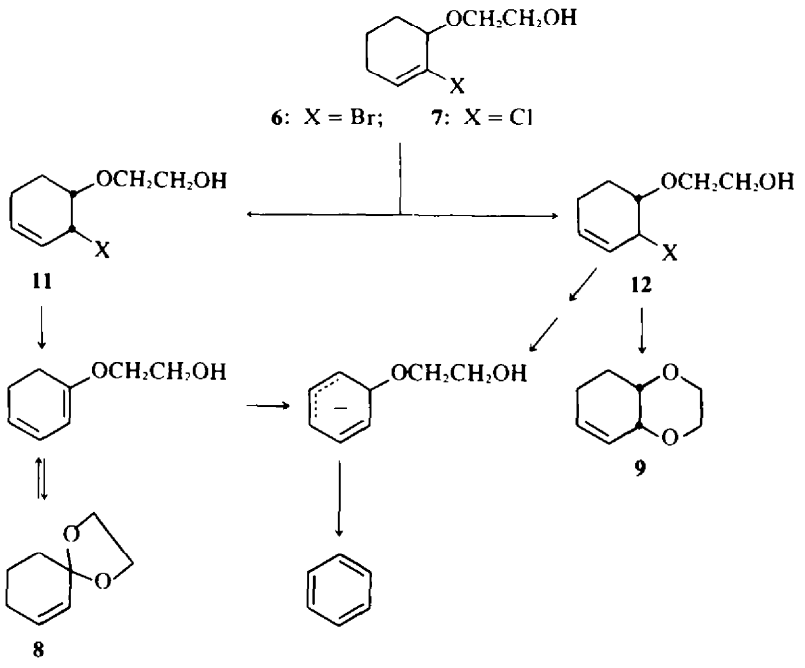
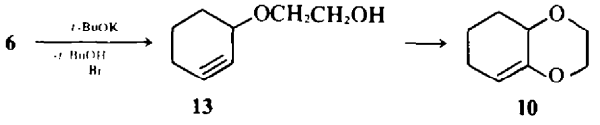
Reactions of simple 1 - halocyclohexenes with *t*-BuOK in DMSO or THF occur in large part by dehydrohalogenation to 1,2-cyclohexadiene as well as dehydrohalogenation to cyclohexyne and prototropic rearrangement to the corresponding 3 - halocyclohexene (Scheme 2).[3] Thus, substitution of a halocyclohexene at C_6 with a 2-hydroxyethoxy group causes the prototropic rearrangement mechanism to predominate and appears to eliminate the 1,2-cyclohexadiene pathway, which is the much more important dehydrohalogenation pathway followed by simple 1 - halocyclohexenes. Two possible explanations were offered[2] to account for the effects of the 2 - hydroxyethoxy group; the anion of the 2 - hydroxyethoxy group could act as a neighbouring group and enhance the prototropic rearrangement to the corresponding 3 - halo - 4 - (2 - hydroxyethoxy)cyclohexene (**11** or **12**); or the alkoxy group could retard formation of the additional multiple bond.

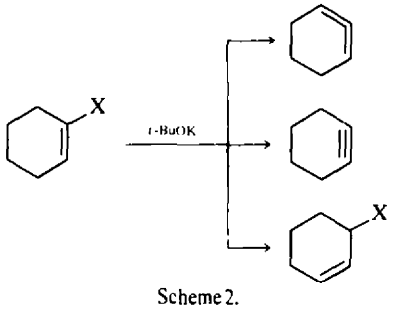
We have described recently the reactions of 1 - bromo - and 1 - chlorocycloheptene[4] and 3 - bromo - and 3 - chlorobicyclo[3.2.1]oct - 2 - ene[5] with *t*-BuOK in DMSO and in THF. In contrast to the reactions of simple cyclohexenes in DMSO, reactions involving prototropic rearrangement of these halocycloalkenes account for very little or no product. Note that prototropic rearrangement of a 3 - halobicyclo[3.2.1]oct - 2 - ene would lead to a compound in violation of Bredt's rule.[6] Thus, study of the reactions of the cycloheptene and 3 - halobicyclo[3.2.1] oct - 2 - ene homologues of **6** and **7** with *t*-BuOK appeared likely to provide a test for these explanations of the role of the 2 - hydroxyethoxy group.

Compounds **2** and **3** were prepared in yields of 38% and 33%, respectively, by treatment of 7,7 - dibromo -[7] and 7,7 - dichlorobicyclo[4.1.0]heptane[7] with 1.2 equivalents of silver nitrate in ethylene glycol.[8] Compounds **4** and **5** were prepared in yields of 85% and 75%, respectively, by treatment of 3,4 - dibromo -[9] and 3,4 - dichlorobicyclo[3.2.1]oct - 2 - ene[10] with 1 equivalent of sodium ethylene glycolate in ethylene glycol. The low yields of the 1 - halo - 7 - (2 - hydroxyethoxy)cycloheptenes (**2** and **3**) are probably the result of highly strained cyclopropyl ring opening pathways.[11] When the 1 - halo - 7 - (2 -



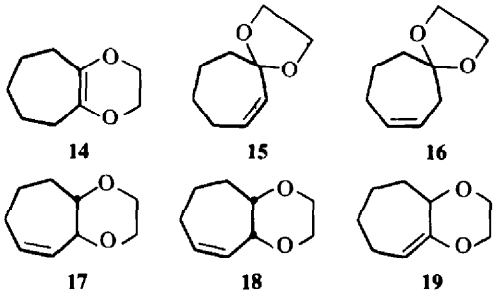
Scheme 1.





Scheme 2.

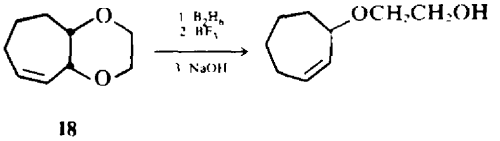
hydroxyethoxy)cycloheptenes were treated with *t*-BuOK in THF the following cyclization products were obtained; 8,11 - dioxyabicyclo[5.3.0]undec - 1(7) - ene **14**, cyclohept - 2 - enone ethylene ketal **15**, cyclohept - 3 - enone ethylene ketal **16**, *trans*- and *cis* - 8,11 - dioxabicyclo[5.4.0]undec - 2 - ene (**17** and **18**), and 8,11 - dioxabicyclo[5.4.0]undec - 1 - ene **19**. With the exception of **19** these products were also obtained when the reactions were carried out in DMSO. The structures of **14–19** were established by a combination of analytical, chemical, and spectral methods.



14 **15** **16**

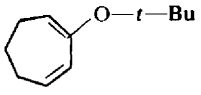
17 **18** **19**

The NMR spectrum of **14** contains no vinyl absorptions; its IR spectrum possesses a very intense band at 1693 cm^{-1}, characteristic of tetrasubstituted olefins bonded directly to oxygen;[12] and a molecular ion with $m/e = 154$ was observed in its mass spectrum. Compound **14** also reacted with mercuric acetate[13] to give a 62% yield of mercury. Cyclohept - 2 - enone ethylene ketal **15** was identified by comparison with a sample prepared by the method of Garbisch.[14] The 3-enone isomer of **16** was also prepared independently by base-induced isomerization of **15** with *t*-BuOK in DMSO. Cycloheptatriene, which is the principal monocyclic product from reactions of **2** and **3** with *t*-BuOK (see below), was also obtained from this reaction. The structures of *trans*- and *cis* - 8,11 - dioxabicyclo[5.4.0]undec - 2 - ene (**17** and **18**) were completely compatible with the analytical and spectral data obtained. With the exception of the cracking patterns seen in the mass spectra, these latter data were very similar for the two compounds. The isomer obtained in significantly larger amounts was assigned the *cis* - configuration on the basis of mechanistic reasoning analogous to that used in consideration of reactions of the cyclohexene homologues **6** and **7** as well as comparison of its NMR spectrum with that of *cis* - 2,5 - dioxabicyclo[4.4.0]dec - 7 - ene **9**. In addition, the *cis* - isomer **18** was also converted in 15% yield to 3 - (2 - hydroxyethoxy)cycloheptene by successive treatment with diborane, boron trifluoride, and sodium hydroxide.[15]



Although 8,11 - dioxabicyclo[5.4.0]undec - 1 - ene **19** was not isolated pure, the identity of this "2 - methylene - 1,4 - dioxane" was established by its ready conversion to the 1,4 - dioxene **14** by either heating to 180° or treating with a trace of acid generated by UV irradiation of carbon tetrachloride. This transformation of **19** to **14** is analogous to similar conversions of 2 - methylene - 1,4 - dioxanes to 1,4 - dioxenes brought about by heat or acid,[1b,2,13] and this particular isomerization was easily monitored by NMR spectroscopy or VPC.

Cycloheptatriene was the major monocyclic product from the reactions of **2** and **3** with *t*-BuOK; it was obtained in yields of 13% (isolated) to 47% (VPC). Also identified, by spectral methods, was a mixture of 1- and 2 - *t* - butoxyl - 1,3 - cycloheptatriene **20**. Another product, obtained in small amounts and also believed to be monocyclic, was not isolated or identified.



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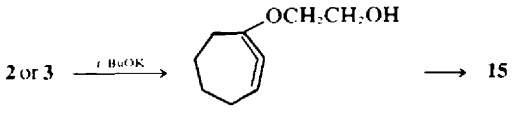
Summarized in Table 1 are yields and product compositions from reactions of **2** and **3** with *t*-BuOK in DMSO and in THF.

Formation of cycloheptatriene can be explained as the result of initial prototropic rearrangement of **2** and **3** to the corresponding *cis* - and *trans* - 3 - halo - 4 - (2 - hydroxyethoxy)cycloheptene **21**, followed by dehydrohalogenation to, e.g. 1 - (2 - hydroxyethoxy)cyclohepta - 1,3 - diene **22**, isomerization to the 5 - (2 - hydroxyethoxy) - isomer **23**, and elimination of a molecule of ethylene glycol. This mechanism is analogous to that suggested to explain the formation of benzene from the reactions of the 1 - halo - 6 - (2 - hydroxyethoxy)cyclohexenes **6** and **7** with *t*-BuOK.[2]

Relative to the yields of benzene from **6** and **7**, the cycloheptenes **2** and **3** gave significantly more cycloheptatriene in DMSO than in THF. 1 - and 2 - *t* - Butoxy - 1,3 - cycloheptadiene **20**, the other identified monocyclic products from **2** and **3**, probably arise from nucleophilic addition of *t*-butoxide to cycloheptatriene.

Formation of cyclohept - 2 - enone ethylene ketal **15** and its isomer **16**, as well as *trans* - and *cis* - 8,11 - dioxabicyclo[5.4.0]undec - 2 - ene (**17** and **18**), can also be explained on the basis of mechanisms similar to those proposed to rationalize the formation of analogous products from the cyclohexenes **6** and **7**.[2] Specifically, **15**, and **16** as well, can be pictured as arising from intramolecular conjugate addition of the alkoxide of 1 - (2 - hydroxyethoxy)cyclohepta - 1,3 - diene **22**, and **17** and **18** could be formed by intramolecular nucleophilic displacement of halide ion by alkoxide from *cis* - and *trans* - 3 - halo - 4 - (2 - hydroxyethoxy)cycloheptene. Interestingly, **15** appears to be converted slowly to **16** and cycloheptatriene under the reaction conditions in DMSO. An alternative but, in our opinion, less likely pathway to **15** and **16** is dehydrohalogenation of **2** or **3** to the cyclic allene **24**, which then undergoes intramolecular nucleophilic addition of alkoxide at C_1 to form the anion of **15**. Such a reaction has analogies in reactions of acyclic 1 - (2 - hydroxyethoxy)allenes.[1b] Note that if all **15** is formed via **24**, this would require that **16** arises solely by prototropic rearrangement of **15**.



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Formation of 8,11 - dioxabicyclo[5.4.0]undec - 1(7) - ene **14** in yields of 6.8 and 4.3% from reactions in DMSO of *t*-BuOK with **2** and **3**, respectively, represents good

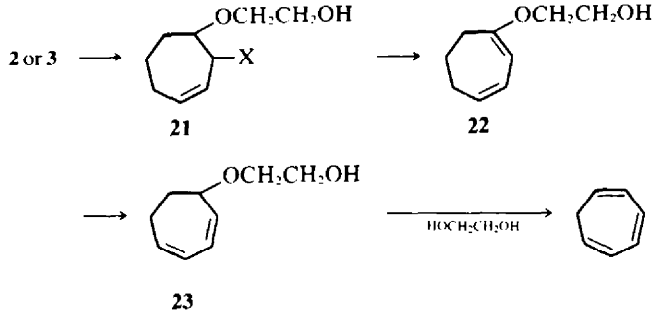


Table 1. Product yields from reactions of 1-halo-7-(2-hydroxyethoxy)cycloheptenes with *t*-BuOK at 65°

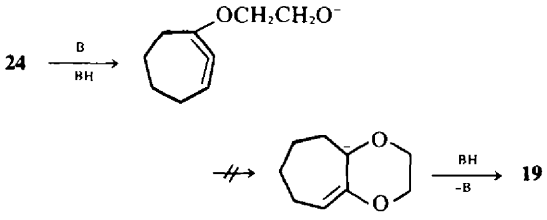
Compound	Solvent	CHF	% Yield†							Residue
			20	**14**	**15**	**16**	**17**	**18**	**19**	(%)‡
2	DMSO	13	—	6.8	1.8	2.0	4.0	15	—	13
3	DMSO	24	0.5	4.3	1.7	2.0	3.2	24	—	17
2	THF	16	1.1	1.7	1.4	0.4	0.5	13	4.8	19
3	THF	47§	1.8	Tr	0.7	0.6	0.1	2.0	2.6	14

†Unless stated otherwise yields are isolated yields for cycloheptatriene (CHT) and **20**; **14–19** were isolated as a single fraction, and yields of individual components were estimated by VPC.

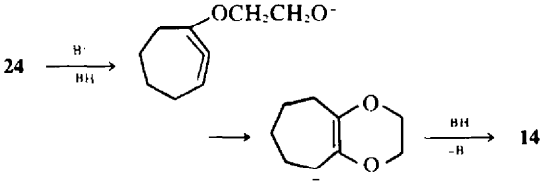
‡Yield based on complete dehydrohalogenation.

§Estimated by VPC.

evidence for the intermediacy of the cyclic allene 1 - (2 - hydroxyethoxy)cyclohepta - 1,2 - diene **24**. Significantly, 8,11 - dioxabicyclo[5.4.0]undec - 1 - ene **19**, which was observed as a product in THF, was not seen as a product from reactions in DMSO. Formation of **14** from **24** without concurrent formation of **18** has analogies in reactions of acyclic 1 - (2 - hydroxyethoxy)allenes.[1b] Note that if nucleophilic addition to **24** was to result in formation of **19**, a tertiary carbanion alpha to oxygen, with its two nonbonding electron pairs, would have to be generated.

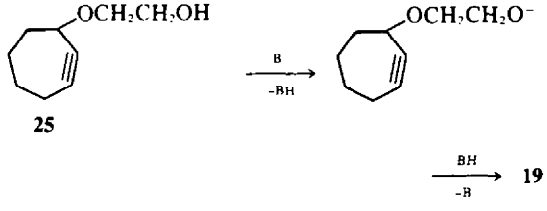


This would be a much less favorable situation than that involved in formation of **14**, where only a secondary carbanion needs to be generated.



It should be added here that **19** was stable with respect to **14** under the reaction conditions but could be converted to **14** by treatment with a trace of acid or heating to 180°.

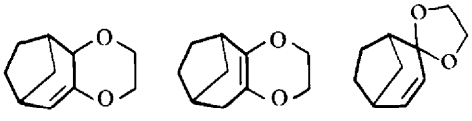
When the solvent was changed to THF, **19** was obtained from **2** and **3** in yields of 4.8 and 2.6%, respectively. At the same time, yields of **14** were reduced to 1.7% and nil, respectively. Note that **19** is the homologue of 2,5 - dioxabicyclo[4.4.0]dec - 6 - ene **10**, which was obtained only in THF. It is evident that **19** also arises by intramolecular nucleophilic addition of alkoxide to a cycloalkyne, specifically, 3 - (2 - hydroxyethoxy)cycloheptyne **25**.



The relative importance of the proposed mechanisms involving the cyclic allene **24** and the cycloalkyne **25** is in accord with the behavior of simple 1 - halocycloalkenes when treated with *t*-BuOK. With these reactions,[3-5] change of solvent from DMSO to THF increases the importance of pathways via the cycloalkyne relative to those via the corresponding cyclic allene.

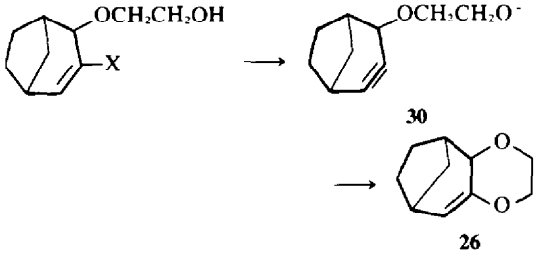
Although the elimination - addition mechanisms account for a greater percentage of products from reactions of the 1 - halocycloheptenes **2** and **3** than of the 1 - halocyclohexenes **6** and **7**, the most important pathway is still that involving prototropic rearrangement to the corresponding allylic halide. We ascribe this to the ability of the alkoxide of the 2 - hydroxyethoxy function to act as a neighbouring group in abstracting a proton from the C_3 of the halocycloalkene.

Three cyclization products were identified as products from reactions of the 3 - halo - **4** - (2 - hydroxyethoxy)bicyclo[3.2.1]oct - 2 - enes **4** and **5** with *t*-BuOK. They were exo - 4,7 - dioxatricyclo[7.2.$1.0^{3,8}$]dodeca - 2 - ene **26**, 3,6 - dioxatricyclo[7.2.$1.0^{2,7}$] - dodeca - 2(7) - ene **27**, and bicyclo[3.2.1]oct - 3 - ene - 2 - one ethylene ketal **28**. The former two compounds were identified by analytical and spectral methods; in addition, **26** was converted to **27** on treatment with a trace of acid generated by UV irradiation of carbon tetrachloride. Compound **28** was synthesized independently in poor yield from the corresponding ketone[16] using the method of Garbisch.[14] Other products **29** believed to include the diastereomer of **26** were also formed in these reactions but were not isolated.

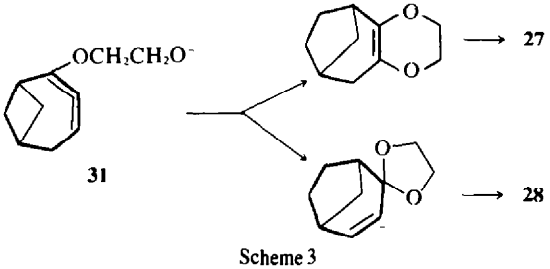


Not unexpectedly, no C_8 hydrocarbon was isolated from reactions of **4** and **5** with *t*-BuOK. Yields and products compositions from reactions of **4** and **5** with *t*-BuOK in DMSO at 35° and 65° and THF at 65° are summarized in Table 2.

In THF and, at 35°, in DMSO, **26** accounts for 90–96% and 78–84%, respectively of the cyclization products from **4** and **5**. The only reasonable mechanism of formation of **26** is dehydrohalogenation of the 3-halo compounds to the corresponding bicycloalkyne, whose conjugate base **30** undergoes intramolecular nucleophilic addition in the only stereoelectronically allowed way.



Evidence for the intermediacy of the bicycloallene corresponding to **4** and **5**, the conjugate base of which is envisaged as **31**, comes from formation of **27** and **28** in low yield. Proposed pathways leading to these two products are shown in Scheme 3. Note that there are obvious



Scheme 3

Table 2. Yields and product compositions from reactions of 3 - halo - 4 - (2 - hydroxyethoxy)bicyclo[3.2.1]oct - 2 - enes with *t* - BuOK

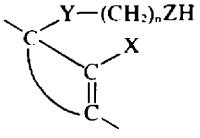
Compound	Solvent	T°	Time (hr)	Yield (%)	Composition (%) 26	27	28	29	Residue (%)†
4	DMSO	35	1.0	80	94	2.4	3.6	0.4	9.7
4	DMSO	65	0.5	78	78	17	2.5	2.5	12.6
5	DMSO	35	42	64	84	3.0	8.0	5.0	20
5	DMSO	65	3.0	69	62	19	8.8	10	22
4	THF	65	1.5	67	96	1.0	2.2	1.0	20
5	THF	65	70	61	90	2.0	2.0	5.7	28

†Yield based on complete dehydrohalogenation.

discrepancies in yields of **24** obtained from both **4** and **5** in DMSO at 35° and 65°. These are due to a slow base-induced isomerization of **26** to **27** which occurs in that solvent at the higher temperature.

Comparison of the results obtained for **4** and **5** with those for the simple 3 - halobicyclo[3.2.1]oct - 2 - enes[5] shows that the corresponding bicycloalkyne intermediates are more important, relative to the bicycloallene, in reactions of **4** and **5**, particularly in THF. The predominance of the bicycloalkyne pathway in reactions of **4** and **5** indicates that considerable carbanionic character is developed at C_4 in the transition state leading to the allene, and this development of partial negative charge is slowed by the presence of the ether oxygen.

Our experience with the substituted cycloalkenes **2–6** and their acyclic analogues[1] leads us to these speculations regarding possible base-induced reactions of analogues such as **32**. Those compounds that are capable of



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$$Y = O, {}^{-}S, NR, \overset{|}{\underset{|}{C}}; \quad Z = O, S, NR, \overset{|}{\underset{|}{C}}$$

undergoing prototropic rearrangement are very unlikely to give a significant yield of cyclic products derived from the corresponding allene or acetylene intermediates. In DMSO, such compounds could give poor to satisfactory yields of cyclization products from intramolecular displacement of the allylic halide formed on prototropic rearrangement, and satisfactory predictions of relative yields of these products should be possible from consideration of the ease of attainment of the reasonably well-defined transition states required; however, these products are likely to be contaminated with small to significant amounts of cyclic products formed by nucleophilic addition to conjugated dienes formed by elimination of the allylic halide. In THF or other nonpolar solvents, these compounds that can undergo prototropic rearrangement, and which bear a group such as OR, SR or NR_1R_2 on cyclic carbon, are likely to give the cyclic triene as the major product together with little if any cyclization product. Those compounds that are not capable of undergoing prototropic rearrangement are likely to give good to excellent yields of cyclization products derived from the corresponding acetylene and/or allene.

EXPERIMENTAL

Sublimed potassium *t*-butoxide (*t*-BuOK) was obtained from MSA Research Corporation and resublimed before use. All dimethyl sulphoxide (DMSO) used had been passed through a column of basic alumina, Activity 1, and distilled from 3 Å molecular sieves at reduced pressure. Tetrahydrofuran (THF) was distilled from lithium aluminum hydride before use. Temperatures are uncorrected. Unless stated otherwise, yields are uncorrected for recovered starting material. IR spectra were obtained with either a Beckman IR-8 or Perkin Elmer 237B spectrophotometer. For samples obtained by prep VPC and available in only μl quantities, IR spectra were obtained using micro NaCl plates with the Beckman IR-8 fitted with a beam condenser. NMR spectra were obtained at 60 MHz with a Varian Associates A60A spectrometer or 100 MHz with a Jeolco Minimar, spectra were taken of 10–20% solutions in CCl_4, using TMS as internal standard. Mass spectra were determined with a Consolidated Electrodynamics Corp. Type 21–104 mass spectrometer; an ionizing voltage of 70 eV was used. VP chromatograms were obtained with an Aerograph Model 600-D, an Aerograph Model 90-P, or an F. and M. Model 810. Elemental analyses were carried out by the Microanalytical Laboratory, University of California, Berkeley, or Chemalytics, Inc., Tempe, Arizona.

1 - *Bromo* - 7 - (2 - *hydroxyethoxy*)*cycloheptene* **2**.[6] To a rapidly stirred solution of silver nitrate (58.3 g, 0.34 mole) in dry ethylene glycol (500 ml) at 80–85° under N_2 was added dropwise, during 2.5 h, 75.8 g (0.30 mole) of 7,7 - dibromobicyclo[4.1.0]heptane.[7] The temperature was increased to 110°, and the mixture was stirred for an additional 6 h. The mixture was cooled to room temperature and filtered to remove the AgBr (60.7 g, 94%), which was rinsed several times with ether. The organic filtrates were combined, poured into ice water (1000 ml), and the aqueous mixture extracted with ether (5 × 200 ml). The ether solns were combined, washed successively with satd NaCl soln (200 ml), water (3 × 200 ml), and satd NaCl soln (200 ml), and dried ($MgSO_4$). Distillation gave 26.5 g (38%) of **2**: b.p. 90–105° (0.4 mm); n_D^{25} 1.5196; NMR, δ 6.37 (t, 1, J = 7 Hz, C = CH), 4.16 (d, 1, J ~ 5 Hz, HC–O), 3.62 (m, 4, OCH_2CH_2O), 3.28 (s, 1, OH), and 2.6–1.1 ppm (m, 8, $[CH_2]_4$). (Found: C, 45.92; H, 6.56; Br, 33.84. $C_9H_{15}BrO_2$ requires: C, 45.93; H, 6.43; Br, 33.99%).

1 - *Chloro* - 7 - (2 - *hydroxyethoxy*)*cycloheptene* **3**. To a rapidly stirred solution of silver nitrate (74.6 g, 0.44 mole) in dry ethylene glycol (530 ml) at 135° under N_2 was added, during 0.25 h, 61.3 g (0.37 mole) of 7,7 - dichlorobicyclo[4.1.0]heptane.[7] The mixture was heated at 135–140° for 6 h, cooled, and worked up in a manner similar to that used in the preparation of **2**. Distillation gave 22.7 g (32%) of unreacted dichloride and 15.8 g (33%) of **3**: b.p. 108–110° (1 mm); n_D^{26} 1.4986; NMR, δ 5.98 (t, 1, J = 6 Hz, C = CH), 3.88 (d, 1, J ~ 5 Hz, HC–O), 3.48 (m, 4, OCH_2CH_2O), 3.18 (s, 1, OH) and 2.46–1.14 ppm (m, 8, $[CH_2]_4$). (Found: 56.87; H, 7.78; Cl, 18.41. $C_9H_{15}O_2Cl$ requires: C, 56.69; H, 7.93; Cl, 18.59%).

3 - *Bromo* - 4 - (2 - *hydroxyethoxy*)*bicyclo*[3.2.1]*oct* - 2 - *ene* **4**. To a rapidly stirred solution prepared from sodium (6.9 g, 0.30 mole) and ethylene glycol (300 ml) was added 79.8 g (0.30 mole) of 3,4 - dibromobicyclo[3.2.1]oct - 2 - ene[9] during 1 h. The mixture was stirred overnight at 30° and an additional 1.5 days at 90°. The mixture was cooled, water (900 ml) and ether (300 ml) were added, and the phases separated. The aqueous phase was ether extracted (3 × 200 ml), and the combined ether extracts dried

(Na_2SO_4). Distillation gave 63.3 g (85%) of colourless **4**: b.p. 102–104° (0.4 mm); n_D^{24} 1.5363; NMR, δ 6.28 (d, 1, J = 7.5–8.0 Hz, C = CH), 3.98 (d, 1, J = 2.5–3.0 Hz, C_4–H), 3.64 (apparent s, 4, OCH_2CH_2O), 3.14 (s, 1, OH), 2.72–4.0 (m, 2, C_1–H and C_5–H), and 2.16–1.08 ppm (complex, 6, $[CH_2]_3$). (Found: C, 48.90; H, 5.96; Br, 32.33. $C_{10}H_{15}BrO_2$ requires: C, 48.60; H, 6.12; Br, 33.12%).

3 - *Chloro* - 4 - (2 - *hydroxyethoxy*)*bicyclo*[3.2.1]*oct* - 2 - *ene* **5**. 3,4 - Dichlorobicyclo[3.2.1]oct - 2 - ene[10] (53.2 g, 0.30 mole) was converted to **5** (45.6 g, 75%) using essentially the procedure described for the preparation of the bromo analogue **4**. Compound **5** has b.p. 98–102° (0.3 mm); n_D^{24} 1.5157; NMR, δ 6.22 (d, 1, J = 7.5 Hz, C = CH), 3.75 (apparent s, 4, OCH_2CH_2O), 3.44 (d, 1, J = 2.5–3.0 Hz, C_4–H), 3.32 (s, 1, OH), 2.84–2.36 (m, 2, C_1–H and C_5–H), 2.17–0.90 ppm (m, 6, $[CH_2]_3$). (Found: C, 59.36; H, 7.48; Cl, 17.20. $C_{10}H_{15}O_2Cl$ requires: C, 59.25; H, 7.47; Cl, 17.49%).

Reactions of the 1 - *halo* - 7 - (2 - *hydroxyethoxy*)*cycloheptenes with t* - *BuOK in DMSO*. The following is representative. To a stirred solution of *t*-BuOK (11.4 g, 0.102 mole) in DMSO (136 ml) at 65° under N_2 was added dropwise 20.0 g (0.085 mole) of 1 - bromo - 7 - (2 - hydroxyethoxy)cycloheptene **2**. When the addition was complete (<7 min), the mixture was checked by VPC (5′ × ¼″ 5% SE30 on 60/80 Chromosorb W, 145°), and there appeared to be no starting material left. The mixture was stirred for 0.5 h, cooled with an ice bath, and quenched with 50 ml of satd K_2CO_3 soln. The mixture was extracted continuously overnight with ether (250 ml), the phases were separated, and the ether phase was washed with satd K_2CO_3 soln (2 × 100 ml), dried (K_2CO_3), and concentrated by distillation through a spinning band column. The concentrate was transferrred to a semi-micro apparatus, and all the volatile components (11.0 g) were collected at high vacuum, the receiver being cooled in a dry ice-acetone bath. There remained a residue of 1.75 g (13% based on complete dehydrohalogenation).

The volatile concentrate (11.0 g) was checked by VPC (5′ × ¼″ 5% SE30) and found to contain a large amount of *t*-butyl alcohol, so this fraction was concentrated further by distillation through a spinning band column. The remaining *t*-butyl alcohol and cycloheptatriene were collected under vacuum in a receiver cooled with a dry ice-acetone bath. The cycloheptatriene (1.01 g, 13%) was isolated from this 1.68 g mixture by prep VPC (5′ × ⅜″ 20% SF 96 on 30/60 chromosorb W). The concentrate that remained after the vacuum removal of *t*-butyl alcohol and cycloheptatriene was distilled through a semi-micro Vigreaux column to give 3.88 g (29.5%) of mixture of $C_9H_{14}O_2$ isomers. Investigation of this mixture by VPC (4′ × ¼″ 5% TCEPE on 60/80 Chromosorb P NAW) indicated the presence of five products: A (6.7%), B (1.3%), C (2.0%), D (3.8%) and E (15.8%). Results from use of a 500-ft capillary Carbowax 20 M column were: A (6.9%), B (2.5%), C (2.4%), D (3.9%) and E (13.8%). The average of 4 individual runs on three different columns were: A (6.8%), B (1.8%), C (2.0%), D (4.0%) and E (14.9%). Each of the five components was isolated by prep VPC (4′ × ¼″ 5% TCEPE or 16′ × ¼″ XF-1150 on 60/80 Chromosorb W HMDS) and identified.

A. 8,11 - *Dioxabicyclo*[5.4.0]*undec* - 1(7) - *ene* **14**. $n_D^{25.5}$ 1.4866; IR, 1693 cm^{-1} (s, ROCR = CR–OR'[12]); NMR, δ 3.9 (s, 4, OCH_2CH_2O), 2.17–1.90 (m, 4, CH_2C = C–CH_2), and 1.9–1.33 ppm (m, 6, R–$CH_2CH_2CH_2$–R); MS, *m/e* (relative intensity) 155 (4), 154 (39), 98 (54), 69 (33), 55 (100). (Found: C, 70.08; H, 8.85. $C_9H_{14}O_2$ requires: C, 70.10; H, 9.15%).

B. *Cyclohept* - 2 - *enone ethylene ketal* **15**. This compound had retention times identical with those of a synthetic sample[14] on three different VPC columns (500′ capillary Carbowax 20 M, 4′ × ¼″ 5% TCEPE, and 16′ × ¼″ 20% XF-1150). Also, the NMR spectrum of the isolated sample was identical with that of the synthetic sample.

C. *Cyclohept* - 3 - *enone ethylene ketal* **16**, this compound had retention times identical with those of a synthetic sample (see below) on the three different VPC columns listed under B. The NMR spectrum was identical with that of the synthetic sample.

D. *trans* - 8,11 - *Dioxabicyclo*[5.4.0]*undec* - 2 - *ene* **17**. n_D^{24} 1.4933; IR 1645 cm^{-1} (w, C=C); NMR, δ 5.85 (m, 2, HC = CH), 4.17–2.83 (m with apparent s at δ 3.75, 7, C_1–H, OCH_2CH_2O, C_7–H and one C_4–H) and 2.83–1.5 ppm (m, 5, one C_4–H, C_5H_2, and C_6–H_2); MS, *m/e* (relative intensity) 155 (4), 154 (38), 112 (20), 101 (6), 100 (100), 99 (69). (Found: C, 70.12; H, 8.96. $C_9H_{14}O_2$ requires: C, 70.10; H, 9.15%).

E. *cis* - 8,11 - *Dioxabicyclo*[5.4.0]*undec* - 2 - *ene* **18**. n_D^{24} 1.4960; IR 1650 cm^{-1} (w, C=C); NMR, δ 6.17–5.34 (m, 2, HC=CH), 4.28 (broad, 1, C_1–H), 4.08–3.16 (m with apparent s at δ 3.75, 5, C_7–H and OCH_2CH_2O), 2.68–1.17 ppm (m, 6, C_4–H_2, C_5–H_2, C_6–H_2); MS, *m/e* (relative intensity) 155 (4), 154 (39), 112 (20), 101 (3), 100 (31), 99 (43), 32 (100). (Found: C, 70.27; H, 9.08. $C_9H_{14}O_2$ requires: C, 70.10; H, 9.15%).

Reactions of the 1 - *halo* - 7 - (2 - *hydroxyethoxy*)*cycloheptenes with t* - *BuOK in THF*. The following is representative. To a stirred solution of *t*-BuOK (21.2 g, 0.187 mole) in THF (250 ml) at 65° under N_2 was added dropwise 16.2 g (0.085 mole) of 1 - chloro - 7 - (2 - hydroxyethoxy)cycloheptene **3**. The reaction was exothermic, and the solution boiled vigorously during the addition. After 0.5 h the reaction mixture was cooled, satd K_2CO_3 soln (50 ml) was added, and the mixture that resulted was poured into water (300 ml). The phases were separated, and the aqueous phase was extracted with ether (3 × 150 ml). The organic phases were combined, washed with water (2 × 100 ml), and dried (K_2CO_3); and the solvent removed by distillation. The concentrate was distilled through a semi-micro Vigreaux column to give four fractions: (1) 4.63 g, to b.p. 38° (760–5 mm); (2) 1.07 g (8.2%), b.p. 63–68° (5 mm); (3) 2.24 g (14%), b.p. 95–98° (0.1 mm) (unreacted **3**); and (4) 1.76 g (13.5% based on complete dehydrohalogenation) of a black, gummy residue.

Fraction (1) was analyzed by VPC (7′ × ¼″ Apiezon J on 45/60 Chromosorb A) and found to be 80.5% (47% actual yield) cycloheptatriene and 19.5% *t*-butyl alcohol. The analysis was confirmed by examination of the NMR spectrum of the mixture.

Fraction (2) was analyzed by VPC (4′ × ¼″ 5% TCEPE and 500′ capillary Carbowax 20 M) and found to consist of A (trace), B (0.7%), C (0.6%), D (0.1%), E (2.0%), F (1.8%), G (2.6%), and H (0.4%). Compounds A–E were found to be the same as those identified in the preceding experiment. Identification of F and G is described below. Compound H was not isolated or identified.

F. 1 - *and* 2 - *t* - *Butoxy* - 1,3 - *cycloheptadiene* **20**. (Spectral data provided evidence for the proposed structures) n_D^{24} 1.4886; NMR, 6.05–5.17 (m, 3, olefin H), 2.5–1.0 (m, 15), including s at 1.18 ($C[CH_3]_3$) and s at 1.10 ppm ($C[CH_3]_3$) (the singlets at δ 1.18 and 1.10 have relative peak heights of 83:17); MS, *m/e* (relative intensity) 166 (3), 110 (100), 109 (20), 95 (85), 93 (12), 91 (15).

G. 8,11 - *Dioxabicyclo*[5.4.0]*undec* - 1 - *ene* **19**, although this compound was not isolated, evidence was obtained for its existence. When the distilled mixture of A–H was injected on to a VPC column (4′ × ¼″ 5% TCEPE) with a cool injection port (<130°), a chromatogram was obtained in which peaks due to D and G were unresolved shoulders of the peak due to E. When the injector port was heated to 175–180° and the same sample was injected, the peak due to A was greatly enhanced, and the peak due to E became more symmetrical.

Reaction of 8,11 - *dioxabicyclo*[5.4.0]*undec* - (7) - *ene* **14** *with mercuric acetate*. Following the procedure of Summerbell *et al.*[13] for the reaction of dioxene with mercuric acetate, to **13** (100 mg, 0.65 mmole) was added 207 mg (0.65 mmole) of mercuric acetate dissolved in water (1.75 ml). A white percipitate formed immediately, which, when left in the dark overnight, became black. Filtration through a tared Gooch crucible gave 81 mg (62%) of shiny mercury.

Cyclohept - 3 - *enone ethylene ketal* **16**. To a solution of *t*-BuOK (1.46 g, 0.013 mole) in DMSO (42 ml) at 65° under N_2 was added 4.0 g (0.026 mole) of cyclohept - 2 - enone ethylene ketal **15**.[14] A reaction began immediately, and after 40 min the solution became yellow brown. Although the rearrangement was not complete after 40 min, it was apparent from examination of the VPC (4′ × ¼″ 5% TCEPE) of the reaction mixture that an undesired decomposition was beginning. The mixture was cooled, and satd K_2CO_3 soln (30 ml) and water (160 ml) were added. The mixture was extracted with ether (4 × 50 ml). The ether solutions were combined, washed successively with water and satd NaCl soln, dried (Na_2SO_4), and distilled. Use of a semi-micro Vigreaux column gave three fractions: (1) b.p. to 25° (760 to 1 mm); (2) 1.12 g, b.p. 60–70° (5 mm); and (3) 0.4 g of residue.

The first fraction yielded 320 mg (13%) of cycloheptatriene isolated by prep VPC (7′ × ¼″ 15% Apiezon J on 45/60 Chromosorb A).

Analysis of the second fraction (1.12 g, 28%) by VPC (4′ × ¼″ 5%

TCEPE) and NMR spectroscopy indicated that it consisted of 13% cyclohept - 2 - enone ethylene ketal **15** and 87% cyclohept - 3 - enone ethylene ketal **16**. The latter compound was purified by prep VPC (3′ × ⅜″ 5% TCEPE on 30/60 Chromasorb W): n_D^{25} 1.4830; IR, 1651 (m, C=C), 1110 (s) and 1062 cm^{-1} (s, ketal); NMR, δ 5.72 (symm 9 lines, 2, HC=CH), 3.9 (apparent s, 4, OCH_2CH_2O), and 2.48–1.33 ppm (m, 8, $[CH_2]_4$); MS, *m/e* (relative intensity) 154 (3), 153 (1), 126 (4), 125 (13), 100 (17), 99 (100).

3 - (2 - *Hydroxyethoxy)cycloheptene.* To a stirred solution of $AgNO_3$ (6.2 g, 0.0365 mole) in ethylene glycol (30 ml) was added dropwise 5.8 g (0.0323 mole) of 3 - bromocycloheptene.[17] After 2 h, the reaction mixture was filtered to remove the insoluble silver salts, which were washed with ether (50 ml). The ether solution was washed successively with satd NaCl soln (2 × 30 ml) and water (2 × 30 ml), and dried ($MgSO_4$). Distillation gave 2.3 g (41%) of 3 - (2 - hydroxyethoxy)cycloheptene: n_D^{24} 1.4808; NMR, δ 5.8 (m, 2, HC=CH), 4.1–3.3 (complex, 5, $HCOCH_2CH_2$), 2.85 (s, variable, 1, OH) and 2.2–1.2 ppm (complex, 8, $[CH_2]_4$); IR 3400 (broad, OH), 1625 (C=C), 1110 and 1050 cm^{-1} (COC).

Hydroboration - elimination reaction of cis - 8,11 - dioxabicyclo[5.4.0]*undec - 2 - ene* **18**.[15] To a stirred solution of **18** (0.93 g, 6.15 mmole) in dry THF (1.5 ml) under N_2 was added dropwise with a syringe 1.05 ml of a 1.95 M diborane solution. After 2 h, boron trifluoride etherate (0.7 ml, 6.15 mmoles) was added. After 12 h, enough 3 M NaOH soln was added to neutralize the boron trifluoride. The reaction mixture was extracted continuously with ether for 24 h, and the ether soln was washed with water (2 × 25 ml), and dried ($MgSO_4$). The ether was removed by distillation, the last traces at reduced pressure. VPC analysis of the residue, which weighed 0.333 g, indicated that it contained 140 mg (15%) of 3 - (2 - hydroxyethoxy)cycloheptene. The presence of 3 - (2 - hydroxyethoxy)cycloheptene was confirmed by its isolation by prep VPC and comparison of its IR and NMR spectra with the product from 3 - bromocycloheptene and ethylene glycol.

Reactions of the 3 - halo - 4 - (2 - hydroxyethoxy) bicyclo[3.2.1]*oct - 2 - enes with t - BuOK in THF.* Compound I was subsequently identified as 3,6 - dioxatricyclo[7.2.1.$0^{2,7}$]dodec - 2(7) - ene **27** by comparison with a sample prepared from **26** (see below).

Compound J was subsequently identified as **28**, the ethylene ketal of bicyclo[3.2.1]oct - 3 - ene - 2 - one, by comparison with a sample prepared from the corresponding saturated ketone using an appropriate modification of the method of Garbisch[14] (see below).

The mixture designated K was not identified.

Compound L was identified by means of its spectral properties as 4,7 - dioxa - tricyclo[7.2.1.$0^{3,8}$]dodec - 2 - ene **26**: IR, 1668 cm^{-1} (s, C=C); NMR, δ 5.38 (d, J = 7.5 Hz, 1, =CH), 3.77 (m, 4, OCH_2CH_2O), 3.40 (d, J = 2 Hz, 1, C_8–H) and 2.8–1.0 ppm (m, 8); MS, *m/e* (relative intensity) 167 (2), 166 (13), 165 (1), 139 (1) 138 (6), 137 (100), 136 (2), 126 (2) and 125 (38). (Found: C, 72.03; H, 8.82. $C_{10}H_{14}O_2$ requires: C, 72.26; H, 8.49%).

Reactions of the 3 - halo - 4 - (2 - hydroxy-ethoxy)bicyclo[3.2.1]*oct - 2 - enes with t - BuOK in DMSO.* The following is representative. To a stirred solution of *t*-BuOK (12.2 g, 0.108 mole) in DMSO (140 ml) at 65° under N_2 was added dropwise 9.92 g (0.049 mole) of **5**. During the reaction, the clear, pale-yellow solution became a thick, brown–black slurry. After 3 h the reaction mixture was cooled, and the reaction was quenched with satd K_2CO_3 soln (30 ml). The mixture that resulted was added to water (500 ml) and extracted continuously overnight with ether (200 ml). The phases were separated, and the ether soln was washed with satd K_2CO_3 soln (2 × 50 ml), and dried (K_2CO_3). Distillation gave 5.63 g (69%) of a mixture of $C_{10}H_{14}O_2$ isomers with b.p. 72–82° (5 mm) and 1.79 g (22% based on complete dehydrohalogenation) of a brown–black residue.

The mixture of $C_{10}H_{14}O_2$ isomers was examined by VPC (500′ capillary Carbowax 20 M) and the same products obtained from reactions in THF were observed. The relative amounts were: I **27** 18.8%; J **28** 8.8%; K (unknown) 10.4%; and L **26** 62.0%. The NMR spectrum of the mixture was in accord with the isomer distribution determined by VPC.

Ethylene ketals of 3 - bromobicyclo[2.2.2]*octan - 2 - one and 3 - bromobicyclo*[3.2.1]*octan - 2 - one.* The procedure used was essentially that used by Garbish[14] for the preparation of the ethylene ketal of 2 - bromocycloheptanone. To bicyclo[3.2.1]octan - 2 - one[16] (22.4 g; 0.18 mole) in ethylene glycol (250 ml) at 20–30° was added dropwise 28.8 g (0.18 mole) of bromine. The addition of bromine was carried out in about 1 h at such a rate as to maintain a slight bromine colour. The reaction mixture was cooled, and, with caution, it was added to a mixture of Na_2CO_3 (50 g) and pentane (200 ml). The pentane phase was separated and dried ($MgSO_4$). Distillation gave 30.4 g (68%) of a mixture of $C_{10}H_{15}O_2Br$ isomers with b.p. 86–88° (0.35 mm). The mixture was analyzed by VPC (4′ × ⅜″ 10% SE 30), and two symmetrical bands were observed with relative intensities of 80:20.

This mixture (12.35 g, 0.05 mole) and 10 g (0.25 mole) of powdered sodium hydroxide in methanol (50 ml) was heated under reflux for 60 h. The reaction was followed by VPC (4′ × ⅜″, 10% SE 30), and the minor component reacted completely. The major component did not appear to react. After workup,[14] two fractions were isolated by distillation: (1) 920 mg (11%; 56% based on conversion of minor ketal to $C_{10}H_{14}O_2$), b.p. 86–91° (4.8 mm); and (2) 7.85 g (64%; 80% based on recovery of major ketal), b.p. 113–115° (5 mm).

Examination of fraction (1) is described in the immediately following section.

Examination of fraction (2) indicated that it consisted mainly of the ethylene ketal of 3 - bromobicyclo[2.2.2]octan - 2 - one: n_D^{24} 1.5288; NMR, δ 4.3 (m, 5, C_2H and OCH_2CH_2O), and 2.30–1.15 ppm (m, 10); MS, *m/e* (>90) (relative intensity > 10%) 248 (11), 246 (11), 179 (11), 177 (11), 167 (16), 99 (100). (Found: C, 49.43; H, 6.41; Br, 31.69. $C_{10}H_{15}O_2Br$ requires: C, 48.60; H, 6.12; Br, 32.37%).

Bicyclo[3.2.1]*oct - 3 - en - 2 - one ethylene ketal* **28**. Fraction (1) from the immediately preceding experiment was purified by prep VPC (4′ × ¼″ 5% TCEPE) and found to be **28**: n_D^{25} 1.5007; IR 1675 (w) and 1635 cm^{-1} (w); NMR, δ 5.98 (d, J = 10 Hz, 1, C_3–H), 5.14 (d of d, J = 10 Hz and 2 Hz, C_4–H), 3.91 (apparent s, 4, OCH_2CH_2O), 2.6–1.08 ppm (m, 8); MS, *m/e* (relative intensity) 167 (2), 166 (10), 127 (2), 126 (8), 125 (100). (Found: C, 72.03; H, 8.63. $C_{10}H_{14}O_2$ requires: C, 72.26; H, 8.49%).

3,6 - *Dioxatricyclo*[7.2.1.$0^{2,7}$]*dodec - 2(7) - ene* **27**. A solution prepared from 4,7 - dioxatricyclo[7.2.1.$0^{3,8}$]dodec - 2 - ene **26** (4.98 g, 0.030 mole) and carbon tetrachloride (15 ml) was irradiated with a 275-watt G.E. sunlamp and heated gently under reflux for 3 h. Distillation gave 4.02 g (81%) of **27**, b.p. 77–78° (5 mm). The compound distilled colourless, but on exposure to air, even under refrigeration, it became an intense yellow. A sample obtained by prep VPC (4′ × ¼″, 5% TCEPE) gave the following data: n_D^{25} 1.5051; IR, 1698 cm^{-1} (vs); NMR, δ 3.86 (apparent s, 4, OCH_2CH_2O); 2.56–2.10 (m, 3), and 2.10–1.0 ppm (m, 7); MS, *m/e* (relative intensity) 168 (2), 167 (6), 166 (52), 165 (2), 138 (13), 137 (62), 125 (14), 110 (65), 71 (100). (Found: C, 72.26; H, 8.69. $C_{10}H_{14}O_2$ requires: C, 72.26; H, 8.49%).

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