Bromination of Dehydroacetic Acid[1a]

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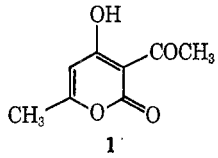
Selective bromination of dehydroacetic acid (1) afforded four different monobromination derivatives. Treatment of 1 with bromine yielded 5-bromodehydroacetic acid (5). A transient product, presumably 5,6-dibromo adduct 6, was detected by nmr. Hydrogen bromide catalyzed bromination of 1 yielded 3β-bromo derivative 9. The thermal (nonphotochemical) reaction of N-bromosuccinimide with 1 and the reaction of bromine with the anion of 1 both gave 3-bromo derivative 4. This compound was highly sensitive to hydrogen bromide, which reconverted it into 1. Photochemical bromination of 1 with N-bromosuccinimide in carbon tetrachloride gave 6α-bromo derivative 14. The 3β,3β-, the 3,5-, and the 3β,5-dibromo derivatives of 1 (10, 13, and 8, respectively) were also prepared. The related compounds, 4-hydroxy-6-methyl-2-pyrone (12) and its methyl ether, on treatment with N-bromosuccinimide, underwent monobromination at the 3 position to give 11 and 15, respectively. Further treatment of 11 with this reagent gave the 3,3-dibromo derivative 16.

Dehydroacetic acid (3-acetyl-4-hydroxy-6-methyl-2H-pyran-2-one) (1) was first prepared more than 100 years ago.[2] Subsequently the chemistry of this compound was investigated extensively. Controversy arose concerning its structure, which was not firmly established until 1924.[3] During the intervening years a bromination product was prepared by Oppenheim and Precht.[4] Although insufficient information was available to make a firm structural assignment for the derivative, structures 2, 3, and 4 were suggested by Perkin,[5] Feist,[6] and Staudinger and Becker,[7] respectively.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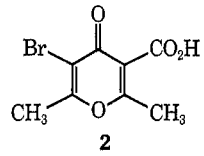
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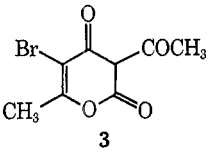
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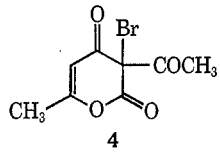
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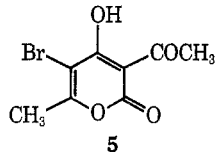
We have now reinvestigated the bromination of dehydroacetic acid, both by direct addition and by other methods, because of the possible utility of the bromo derivatives for the synthesis of complex pyrones. Recent interest in the chemistry of pyrones has stemmed from a possible relationship between their reactions with bases and the biosynthesis of phenolic compounds.[8]

Results and Discussion

The initial studies with dehydroacetic acid involved bromination under the conditions described by the earlier workers,[4-7] because the structure of the resulting monobromination product had not been firmly established. Anhydrous dehydroacetic acid in chloroform was treated with 2.5 equiv of bromine containing 1 mol % iodine.[9,10] The mixture was allowed to stand for 72 hr at 5°. The product (48%) after recrystallization from methanol had the same melting point as had been reported previously. Elemental and mass spectral analysis showed that one hydrogen atom had been replaced by a bromine atom (see spectral section). The nmr spectrum indicated that the site of replacement was the 5 position giving derivative 5, which is the enolized form of structure 3 proposed by Feist.[6]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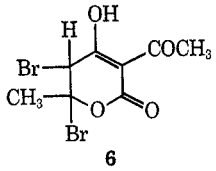
To obtain additional information about the process by which 5 was formed, nmr spectra were recorded of reaction mixtures in deuteriochloroform while the reactions were taking place. Following the addition of bromine, immediate formation of a transient compound occurred. The compound was clearly distinguishable from other bromo derivatives on the basis of its nmr spectrum; in particular, the 5-proton signal was at much higher field than was observed with the other derivatives. Treatment of the solution with excess, aqueous sodium bisulfite caused a decrease in concentration of the compound, seemingly by return to 1. However, the remaining material retained the characteristic spectrum. Adduct 6, but not cation 7, appeared to be compatible with this evidence.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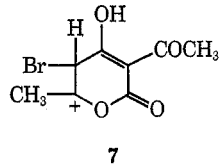
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(2) A. Geuther, *Z. Chem.* (Jena), **2**, 8 (1866); *Chem. Zentr.*, **11**, 801 (1866).

(3) C. F. Rassweiller and R. Adams, *J. Amer. Chem. Soc.*, **46**, 2758 (1924). See also J. A. Berson, *ibid.*, **74**, 5172 (1952); S. Forsen and M. Nilsson, *Arkiv Kemi*, **17**, 523 (1961); E. E. Royals and J. C. Leffingwell, *J. Org. Chem.*, **30**, 1255 (1965).

(4) A. Oppenheim and H. Precht, *Ber.*, **9**, 1099 (1876).

(5) W. H. Perkin, *J. Chem. Soc.*, **51**, 484 (1887).

(6) F. Feist, *Ber.*, **25**, 315 (1892).

(7) H. Staudinger and H. Becker, *ibid.*, **50**, 1016 (1917).

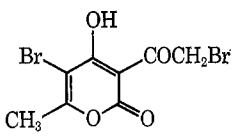
(8) For examples, see T. M. Harris, M. P. Wachter, and G. A. Wiseman, *Chem. Commun.*, 177 (1969); T. Money, F. W. Comer, G. R. B. Webster, I. G. Wright, and A. I. Scott, *Tetrahedron*, **23**, 3435 (1967); J. L. Douglas and T. Money, *ibid.*, 3545 (1967); D. G. Pike, J. J. Ryan, and A. I. Scott, *Chem. Commun.*, 629 (1968); L. Crombie and A. W. G. James, *ibid.*, 357 (1966).

(9) Water appeared to lead to the formation of several unidentified by-products.

(10) The use of iodine had been suggested by Perkin.[5] However, Feist[6] considered it to be superfluous.

In the bromination reaction the concentration of **6** increased for several minutes. During this time the initial formation of **5** was observed, but it was not so fast as that of **6**. The subsequent course of reaction depended upon hydrogen bromide concentration. In tightly capped nmr tubes, where internally generated hydrogen bromide accumulated, acetyl bromination became a more important process than 5 bromination and the concentration of **6** decreased rapidly until it became undetectable. In uncapped tubes, much of the hydrogen bromide escaped and **6** was present for many hours, during which time gradual formation of **5** occurred. Attempts to isolate **6** were unsuccessful, in spite of the fact that under favorable conditions nearly 50% conversion into **6** could be obtained.

Dehydroacetic acid, when treated with 2 equiv of bromine at room temperature for 72 hr, afforded dibromination product **8** in 21% yield. Analysis of the nmr spectrum led to the conclusion that the second bromine atom had been introduced into the acetyl methyl group (see spectral section). Monobromo derivative **5** was treated with bromine in an attempt to synthesize **8** in a stepwise fashion. No reaction occurred until hydrogen bromide was added. Dibromo derivative **8** was isolated subsequently by chromatography. Addition of bromine across the 5,6 double bond of **5** was not observed.



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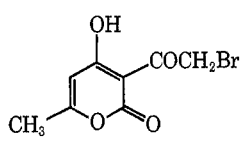
Various reaction conditions were investigated in a search for other bromination products. The observation that hydrogen bromide seemed to catalyze bromination at the acetyl position led to an experiment in which a solution of dehydroacetic acid in chloroform was saturated with hydrogen bromide prior to addition of bromine. The reaction afforded 50% bromoacetylpyrone **9**. Spectroscopic data confirmed the site of bromination. Surprisingly, further treatment of **9** with bromine gave only a trace of **8**; the major product (77%) was the geminal dibromo derivative **10**.



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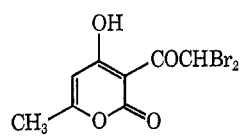

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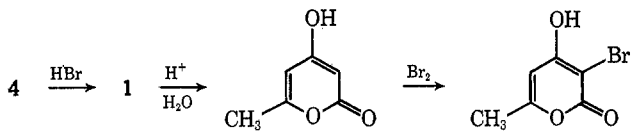
Bromination of dehydroacetic acid with N-bromosuccinimide was explored. 3-Bromodehydroacetic acid (**4**) was obtained as essentially the only product when the reaction was carried out in refluxing chloroform in darkness with a small amount of iodine as a catalyst. This bromo derivative was a liquid and decomposed on attempted distillation. The ir spectrum of **4** showed the presence of three distinguishable types of carbonyl groups.

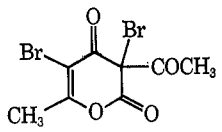
The compound was also obtained by bromination of the anion of **1**. Treatment of the anhydrous sodium salt of **1** suspended in chloroform with 1 equiv of bromine caused immediate precipitation of sodium bromide and disappearance of the bromine color. Evaporation of the supernatant solution gave a 77% yield of **4**.

In contrast to the other bromopyrones which were relatively insensitive to anhydrous hydrogen bromide, compound **4** reacted instantaneously with it to give **1** and bromine. When this acidified mixture was allowed to stand for several hours, rebromination of **1** occurred forming **5** and **9**. A small amount of 3-bromo-4-hydroxy-6-methyl-2-pyrone (**11**) was isolated after **4** had been allowed to stand in contact with moist air for several days. This compound probably arose by conversion of **4** into dehydroacetic acid, deacetylation to form pyrone **12**, and rebromination (see below). However, direct deacetylation of **4** cannot be excluded rigorously.



12 **11**

Interestingly, when the reaction of **1** with N-bromosuccinimide was carried out in the absence of iodine, a mixture of **4**, **5**, and a compound identified as dibromopyrone **13** was obtained. The source of the iodine effect is not understood. Dibromopyrone **13** was prepared directly and efficiently by treatment of **5** with N-bromosuccinimide and a catalytic amount of iodine in darkness. The compound was an unstable oil having an ir spectrum similar to that of **4**. Likewise, it reverted to **5** upon treatment with anhydrous hydrogen bromide.



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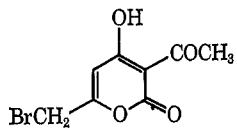
Free-radical bromination of dehydroacetic acid afforded a fourth monobromination product. Dehydroacetic acid was treated with N-bromosuccinimide in carbon tetrachloride at ambient temperature in the presence of light from a sun lamp. The nmr spectrum of the product (**14**) indicated that bromine substitution had occurred at the 6-methyl position. None of the other monobromination products (**4**, **5**, and **9**) was detected. However, the nmr spectrum of the crude reaction mixture suggested that di- and possibly trisubstitution had occurred at the 6-methyl position. The photochemical reaction is undoubtedly a free-radical reaction involving abstraction of a hydrogen atom from the 6-methyl position. The high degree of selectivity toward the 6-methyl position may reflect the substantial resonance stabilization of the resulting radical.



14

The 3 position of dehydroacetic acid appears to be the most susceptible to electrophilic substitution, in

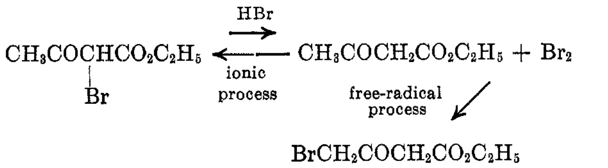
spite of the fact that reaction with molecular bromine was not observed at that position. The reaction of the anion of **1** with molecular bromine and the thermal reaction of **1** with N-bromosuccinimide both afford high yields of 3-bromo derivative **4**. However, **4** is extremely sensitive to hydrogen bromide and undergoes instantaneous and essentially quantitative debromination. We conclude that the reaction of **1** with molecular bromine to form **4** and hydrogen bromide is facile but lies far toward the side of starting materials.

$$1 + Br_2 \rightleftharpoons 4 + HBr$$

5-Bromo adduct **5** arises by a slower but less reversible reaction of **1** with molecular bromine; adduct **6** appears to be in a relatively slow equilibrium with **1** and bromine. The adduct may be an intermediate in the formation of **5**, but this point is difficult to prove. Alternatively, bromination may involve only the undetected cation **7**; interconversion of **1** (or of **7**) and **6** may play no essential part in the formation of **5**.

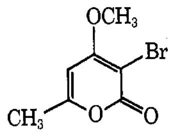
Hydrogen bromide inhibits the formation of **6** to a lesser extent than it inhibits the formation of **4**. Whereas in the latter reaction hydrogen bromide is a product and can participate directly in the reverse reaction, in the formation of **6** it merely serves to reduce the concentration of free dehydroacetic acid by conversion into the pyrylium ion.[11] Hydrogen bromide causes the site of bromination to shift to the acetyl position presumably as a result of acid-catalyzed enolization and simultaneous deactivation of the 5 position by pyrylium salt formation.

The influence of reaction conditions on the site of halogenation has been observed in other enolic systems.[12] The bromination of ethyl acetoacetate provides an interesting comparison with the present system. The initial site of substitution is the 2 position, but intermolecular rearrangement to the 4 position occurs in the presence of hydrogen bromide and free-radical initiators. The rearrangement reaction has been studied in detail.[13] Debromination of the 2-bromo ester is an acid-catalyzed, ionic process. Debromination, although facile, is reversible and the equilibrium lies almost entirely on the side of the 2-bromo ester. Rebromination at the 4 position is primarily a free-radical process; there is little tendency for acid-catalyzed enolization to occur at that position.



The bromination of dehydroacetic acid (**1**) differs from that of ethyl acetoacetate in two respects. First, removal of bromine from the 3 position of **1** by hydrogen bromide is essentially quantitative. Second, there are alternative ionic pathways by which **1** can undergo rebromination to give isomeric products, whereas with ethyl acetoacetate there is none. The two systems are similar to the extent that free-radical bromination is observed at sites not readily substituted by ionic means.

Two related pyrones, **12** and its 4-methyl ether, both underwent bromination exclusively at the 3 position to yield monobromo derivatives **11** and **15**, respectively.[14] Light had no effect on either reaction; both occurred rapidly at ambient temperature. Further treatment of **11** with N-bromosuccinimide gave geminally dibrominated pyrone **16**. Upon standing in air, **16** slowly reverted to pyrone **11**.



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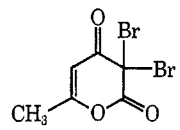

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Spectral Assignments.—The structures of the bromopyrones were assigned on the basis of spectral characteristics. Nmr spectra were particularly helpful in this regard. The nmr spectra of dehydroacetic acid (**1**) and bromo derivatives **4–6**, **8–10**, **13**, and **14** are summarized in Table I.

TABLE I
NMR SPECTRA OF DEHYDROACETIC ACID AND ITS BROMINATION PRODUCTS

Compd	Chemical shifts, δ[a] (relative areas)			
	6-CH_3	3-$COCH_3$	5-H	OH
1	2.30 (3)	2.65 (3)	5.95 (1)	16.7 (1)
4	2.27 (3)	2.48 (3)	5.75 (1)	
5	2.48 (3)	2.70 (3)		18.0 (1)
6	2.34 (3)	2.70 (3)	4.87 (1)	16–18[b] (1)
8	2.52 (3)	4.67 (2)		16.7 (1)
9	2.33 (3)	4.70 (2)	6.06 (1)	15.5 (1)
10	2.35 (3)	7.48 (1)	6.09 (1)	15.0 (1)
13	2.46[c] (3)	2.50[c] (3)		
14	4.13 (2)	2.68 (3)	6.25 (1)	16.7 (1)

[a] Parts per million. [b] Probable location; see text. [c] The relative assignment of the two methyl groups is uncertain.

The 6-methyl group of **1** is shielded with respect to the acetyl methyl group by 0.4 ppm;[15] a similar relationship is observed with the bromo derivatives of **1**.

The acetyl hydrogens of 3-, 5-, and 6α-bromination derivatives of dehydroacetic acid give singlets within the range of δ 2.48–2.70 ppm, whereas the 6-methyl signals of 3-, 3β-, and 5-brominated derivatives appear between δ 2.28 and 2.53 ppm. In spite of the small overlap in these ranges, the structural assignments appear to be secure. Moreover these assignments are supported by mass spectral evidence cited below. The substitution of bromine at either methyl position deshields the resulting methylene group by *ca.* 2 ppm. The chemical shifts of the methylene groups of **9** and **14** retain the same relative relationship as the signals of the acetyl and 6-methyl protons of dehydroacetic acid.

(11) Nmr spectra revealed the formation of the pyrylium ion from **1** in the presence of hydrogen bromide. Gradual downfield shifts were observed when the anhydrous gas was added to chloroform solutions of **1**.

(12) For examples, see K. Arakawa and M. Irie, *Pharm. Bull.* (Tokyo), **5**, 528 (1957); N. Schamp and M. Versele, *Bull. Soc. Chim. Belg.*, **73**, 81 (1964).

(13) M. S. Kharasch, E. Sternfeld, and F. R. Mayo, *J. Amer. Chem. Soc.*, **59**, 1655 (1937); R. Altschul and P. D. Bartlett, *J. Org. Chem.*, **5**, 623 (1940).

(14) Bromopyrone **11** has been prepared previously by treatment of **12** with bromine in glacial acetic acid: F. Arndt and S. Avan, *Chem. Ber.*, **84**, 343 (1951). Bromopyrone **15** has been obtained from **11** by methylation with diazomethane: K. Yamada, *Bull. Chem. Soc. Jap.*, **35**, 1323 (1962).

(15) The assignment is made on the basis of observable allylic coupling between the 6-methyl group and the 5 proton: N. S. Bhacca, D. P. Hollis, L. F. Johnson, and E. A. Pier, Varian NMR Spectra Catalog, Vol. 2, 1963, Spectrum No. 504.

The vinylic 5 proton of **1** and its derivatives occurred near δ 6 ppm. In contrast, 5,6-dibromo adduct **6** produced a singlet at δ 4.87 ppm, reflecting the change of hybridization at the 5 position. The enol signal of **6** could not be observed directly. However, integral traces indicated that the proton gave a peak near δ 17 ppm.

Mass spectra of the monobromo derivatives of dehydroacetic acid (**1**) provided confirmatory structural information (Table II). In **1** methyl loss (*m/e* 153) is a prominent fragmentation process. A comparison of the spectrum of **1** with that of acetyl-deuterated **1** indicated that the methyl group can be lost from either the acetyl group or the 6 position. The former process is the more important of the two. Among the monobromo derivatives of **1**, only the 3β- and 6α-bromo derivatives, **9** and **14**, undergo the corresponding loss of CH_2Br to give *m/e* 153. The fragment ion from **9** is more intense than that from **14**, reflecting the same cleavage preference observed with **1**.

TABLE II

MASS SPECTRA OF DEHYDROACETIC ACID AND ITS MONOBROMO DERIVATIVES[a]

	Compounds, % of base peak				
m/e	**1**	**4**	**5**	**9**	**14**
248		<1[b]	26[b]	10[b]	13[b]
246		<1[b]	26[b]	10[b]	13[b]
178		1	12		
176		1	12		
168	100[b,c]	1[d]		16[d]	11[d]
167			100[c]	100[c]	100[c]
166			8	14	
153	75			100[c]	20
151				18	
140	6				
139				10	20
127				16	
125	39	3	18	8	7
111	18			6	21
98	26				
97	4	3	5		20
93	4	2		17	
85	82	7		62	7
84	16		6		
69	72	26	14	29	25
67		2	11		
55	15	3	10	16	20
53	12	10	10	15	15
43	75	100[c]	68	100[c]	63
42	12			15	13

[a] Spectra were obtained with an LKB-9000 mass spectrometer operated at 70 eV. The samples were introduced by means of the direct insertion probe. Intensities of $\geq$1% are tabulated for all *m/e* values at which one or more of the compounds afforded ions of $\geq$10% intensity. [b] Parent ion. [c] Base peak. [d] Probable contamination by **1**.

The structure of 3,3-dibromopyrone **16** was supported by both nmr and mass spectral evidence. The nmr spectrum was very similar to that of 3-bromopyrone **4** and consisted of signals for the 5 proton and the 6-methyl group at δ 5.74 and 2.3 ppm, respectively. The mass spectrum confirmed the geminal relationship of the bromine atoms; significant ions were $Br_2C{=}C{=}O\cdot^+$ and $CBr_2\cdot^+$.

Experimental Section[16]

Dehydroacetic acid (**1**), obtained from Eastman Organic Chemicals, Inc., was dried *in vacuo* for 12 hr before use. Acetyl-deuterated dehydroacetic acid was prepared by equilibrating 0.40 g (2.3 mmol) of dehydroacetic acid with 5 ml of 2 *M* NaOD in D_2O for 2 hr at ambient temperature. The solution was poured onto a mixture of ice and 3 ml of 12 *M* HCl. Recovered dehydroacetic acid was filtered, dried, and sublimed, mp 109.5–110.5°. Nmr indicated that the relative protium content at the 5,6α,3β, and hydroxyl positions was 1.00, 2.84, 0.19, and 0.96 H, respectively. The mass spectrum indicated the following extent of deuteration: d_0, <0.3; d_1, <0.3; d_2, 5.7; d_3, 77.6; d_4, 12.8; d_5, 2.6; d_6, <0.3; d_7, <0.3; d_8, <0.3%.

5-Bromodehydroacetic Acid (3-Acetyl-5-bromo-4-hydroxy-6-methyl-2H-pyran-2-one, 5).—To a solution of 2.5 g (15 mmol) of **1** in chloroform (35 ml) was added a solution of 6 g (37.5 mmol) of Br_2 and 0.10 g of I_2 in chloroform (35 ml) at 0°. After 72 hr at 5°, the solution was washed with 5% sodium bisulfite solution and evaporated. An ethereal solution of the residue was dried ($MgSO_4$) and evaporated to leave 3.1 g (83%) of crude pyrone **5**, mp 125–135°. Two recrystallizations from methanol gave 1.8 g (48%) of pure **5**: mp 136–138° (lit.[5] mp 137°); ir (KBr) 3400 (OH), 1730 (s, C=O), 1598 (s), and 1540 cm^{-1} (s). Pyrone **5** was stable to hydrogen bromide at ambient temperature and gave no observable reaction with sodium iodide in acetone.

Anal. Calcd for $C_8H_7O_4Br$: C, 38.89; H, 2.86; Br, 32.34. Found: C, 39.08; H, 2.75; Br, 32.55.

Nmr Spectra of Reaction Mixtures.—Mixtures of **1** and Br_2 in $CDCl_3$ were allowed to stand at ambient temperature. Nmr spectra were recorded at frequent intervals. Aliquots were treated with 5% sodium bisulfite solution and spectra were recorded. The chemical shifts prior to bisulfite treatment were at slightly lower field and were dependent upon hydrogen bromide and/or bromine concentration. The chemical shifts (Table I) were highly reproducible after treatment. The procedure caused a decrease in the mole fraction of dibromo adduct **6**. This may result from differences in distribution coefficients of the various compounds between the two phases. However, the disappearance of **6** appeared to result from partial reversion to dehydroacetic acid.

3β,5-Dibromodehydroacetic Acid (5-Bromo-3-bromoacetyl-4-hydroxy-6-methyl-2H-pyran-2-one, 8).—A solution of 2.5 g (15 mmol) of **1** and 5 g (31 mmol) of Br_2 in chloroform (20 ml) was refluxed briefly and allowed to stand for 72 hr at ambient temperature. The solution was washed with 5% sodium bisulfite solution and evaporated. The residue was washed with a small volume of carbon tetrachloride to leave 1.04 g (21%) of dibromopyrone **8**: mp 122–129° and 130–131.5° after recrystallization from chloroform–hexane; ir (KBr) 3405 (s, OH), 1720 (s, C=O), 1610 (s), and 1580–1537 cm^{-1}. The compound gave a weak "positive halogen" test with sodium iodide in acetone.

Anal. Calcd for $C_8H_6O_4Br_2$: C, 29.48; H, 1.86; Br, 49.03. Found: C, 29.72; H, 1.89; Br, 49.08.

The nmr spectrum and tlc of the carbon tetrachloride washings from above indicated that the solution contained **1**, **5**, and several minor components. A singlet at δ 7.45 ppm indicated that one of the latter may have been the dibromoacetyl compound.

No reaction occurred when a solution of 0.5 g (2 mmol) of **5**, 0.5 g (3 mmol) of Br_2, and 0.01 g of I_2 in chloroform (10 ml) was allowed to stand at ambient temperature for 24 hr. Hydrogen bromide was bubbled through the solution briefly and, after an additional 6 hr, nmr indicated that *ca.* 50% conversion into pyrone **8** had occurred. Isolation was more difficult than in the previous preparation; however a small amount (7%) of **8**, mp 129–131°, was obtained by chromatography on silicic acid.

3β-Bromodehydroacetic Acid (3-Bromoacetyl-4-hydroxy-6-methyl-2H-pyran-2-one, 9).—To a HBr-saturated solution of 1.68 g (10 mmol) of **1** in chloroform (15 ml) was added 1.75 g (11 mmol) of Br_2 and 0.05 g of I_2 in chloroform (10 ml). After 24 hr, the solution was washed with 5% sodium bisulfite solution, dried ($MgSO_4$), and evaporated to leave a viscous oil.

(16) All melting points were taken in unsealed capillaries with a heated oil bath and are corrected. Elemental analyses were performed by Galbraith Laboratories, Inc., Knoxville, Tenn. Infrared spectra were determined with a Beckman IR-10 spectrophotometer. Nmr spectra were determined with a Varian A-60 spectrometer using *ca.* 10% solutions in deuteriochloroform. Tetramethylsilane was employed as an internal standard. The ir, nmr, and mass spectrometers were purchased with funds provided by the National Science Foundation.

Trituration with carbon tetrachloride caused crystallization of 1.25 g (50%) of bromopyrone **9**: mp 111–114° and 118–119° after recrystallization from chloroform–hexane; ir (KBr) 3335 (s, OH), 1732 (s, C=O), 1717, and 1641 cm^{-1} (s). The compound gave a weak positive halogen test with sodium iodide in acetone.

Anal. Calcd for $C_8H_7O_4Br$: C, 38.89; H, 2.86; Br, 32.34. Found: C, 39.10; H, 2.80; Br, 32.51.

3β,3β-Dibromodehydroacetic Acid (3-Dibromoacetyl-4-hydroxy-6-methyl-2H-pyran-2-one, 10).—A solution of 1.25 g (51 mmol) of bromopyrone **9** and 0.86 g (54 mmol) of Br_2 in ethanol-free chloroform (15 ml) was stoppered and allowed to stand for 48 hr at ambient temperature, during which time the bromine color disappeared. The solvent was evaporated *in vacuo*. The residue was washed with carbon tetrachloride to afford 1.28 g (77%) of dibromopyrone **10**: mp 81–82.5° and 85–86° after recrystallization from carbon tetrachloride–hexane; ir (KBr) 3400, 1730, 1630, and 1570 cm^{-1}. The compound gave a positive halogen test with sodium iodide in acetone and an intense red color with base.

Anal. Calcd for $C_8H_6O_4Br_2$: C, 29.48; H, 1.86; Br, 49.03. Found: C, 29.52; H, 1.91; Br, 48.92.

3-Bromodehydroacetic Acid (3-Acetyl-3-bromo-3,4-dihydro-6-methyl-2H-pyran-2,4-dione, 4).—Bromine (0.50 g, 3.1 mmol) was added to a suspension of 0.657 g (3.5 mmol) of the anhydrous salt of **1**[17] in ethanol-free chloroform (10 ml). The bromine color was discharged rapidly and after 5 min only a faint yellow color remained. The mixture was filtered and the residue was washed with chloroform. The filtrate and washings were combined and the solvent was removed *in vacuo* to leave 0.592 g (77%) of **4** as a yellow oil: ir (CCl_4) 1801 (s, ester C=O), 1755 (s, $COCH_3$), 1714 (s, 4-C=O), 1654, and 1623 cm^{-1}. Extensive decomposition occurred when distillation was attempted at 0.1 mm. The compound gave an intense positive halogen test with sodium iodide in acetone. Treatment of **4** with hydrogen bromide in chloroform at 0° gave instantaneous formation of bromine and dehydroacetic acid. Bromo derivatives **5** and **9** formed gradually when this mixture was allowed to stand. Bromopyrone **4** underwent a slow reaction with moist air to form a low yield (5%) of 3-bromo-4-hydroxy-6-methyl-2H-pyran-2-one (**11**), mp 203–204° dec (lit.[14] mp 210° dec).

A mixture of 1.5 g (9 mmol) of **1**, 2.0 g (11 mmol) of N-bromosuccinimide, and 0.05 g of I_2 in carbon tetrachloride (20 ml) was refluxed for 2 hr in darkness. The solution was filtered to remove succinimide and evaporated to leave 2.23 g of bromopyrone **4** as a straw-colored oil. The spectral properties of this material were identical with those of **4** prepared with the sodium salt.

3,5-Dibromodehydroacetic Acid (3-Acetyl-3,5-dibromo-3,4-dihydro-6-methyl-2H-pyran-2,4-dione, 13).—A mixture of 0.758 g (3.1 mmol) of **5**, 0.630 g (3.5 mmol) of N-bromosuccinimide, and 0.024 g of I_2 in carbon tetrachloride was refluxed for 1.5 hr in darkness. An nmr spectrum of the supernatant showed singlets of equal area at δ 2.46 and 2.50 ppm. No vinyl or enol proton signals could be detected. The nmr spectrum was unaltered by an additional 4.5 hr of reflux. Succinimide was removed by filtration and the solvent was evaporated to leave dibromopyrone **13** as a yellow oil: ir (neat) 1795 (s), 1760 (w), 1725 (s), 1710 (sh), and 1615 cm^{-1}.

Treatment of 0.367 g (1.1 mmol) of **13** in chloroform with anhydrous hydrogen bromide gave rapid debromination. Evaporation of the solvent left 0.232 g of solid material, the nmr spectrum of which showed the presence of **5** plus a trace of **8**. Recrystallization from methanol gave **5**, mp 132–136°.

6α-Bromodehydroacetic Acid (3-Acetyl-6-bromomethyl-4-hydroxy-2H-pyran-2-one, 14).—A mixture of 1.68 g (10 mmol) of **1** and 2.0 g (11 mmol) of N-bromosuccinimide in carbon tetrachloride contained in a Pyrex flask was irradiated with a 275-W sun lamp for 7 hr at 23°. The mixture was filtered and the filtrate was evaporated. Nmr indicated the residue to be mainly a mixture of **1** and bromo derivative **14**. A small peak at δ 6.95 ppm was tentatively assigned as the 6α proton of 6α,6α-dibromodehydroacetic acid. The crude product was washed with a small volume of ether. Dehydroacetic acid was removed from the residue by sublimation at 40° (0.025 mm). Recrystallization of the remainder from methanol gave 0.58 g (23%) of **14**: mp 113–116° and 117–119° after further recrystallization from methanol: ir (KBr) 3400, 1720, 1640, and 1615 cm^{-1}.

Anal. Calcd for $C_8H_7O_4Br$: C, 38.89; H, 2.86; Br, 32.34. Found: C, 38.95; H, 2.74; Br, 32.25.

3-Bromo-4-hydroxy-6-methyl-2H-pyran-2-one (11).—A mixture of 1.29 g (10 mmol) of 4-hydroxy-6-methyl-2H-pyran-2-one (**12**) and 2.0 g (11 mmol) of N-bromosuccinimide in *t*-butyl alcohol was stirred in darkness for 2 hr at 30°. The usual isolation afforded 1.62 g (77%) of **11**, mp 198–201°. Recrystallization from glacial acetic acid raised the melting point to 203–204° (lit.[14] mp 210° dec). The nmr spectrum of **11** confirmed the location of the bromine atom. Allylic coupling (J = 0.9 Hz) between the methyl group (δ 2.22 ppm) and the 5 proton (6.12) was readily observed. The compound gave an immediate positive halogen test with sodium iodide in acetone.

3-Bromo-4-methoxy-6-methyl-2H-pyran-2-one (15).—A mixture of 0.70 g (5 mmol) of 4-methoxy-6-methyl-2H-pyran-2-one[18] and 1.0 g (5.6 mmol) of N-bromosuccinimide in carbon tetrachloride (25 ml) was stirred for 5 hr in darkness at 50°. Work-up afforded 0.530 g (49%) of bromopyrone **15**: mp 155–156° (lit.[14] mp 151–152°); ir (KBr) 3415, 1740, 1710, and 1640 cm^{-1}; nmr ($CDCl_3$) δ 2.3 (d, 3, J = 0.7 Hz, 6-CH_3), 3.98 (s, 3, OCH_3), and 6.27 ppm (q, 1, J = 0.7 Hz, 5-**H**). The compound gave a weak positive halogen test with sodium iodide in acetone.

3,3-Dibromo-2,3-dihydro-6-methyl-4H-pyran-2,4-dione (16).—A mixture of 1.02 g (5 mmol) of **11**, 1.11 g (6.2 mmol) of N-bromosuccinimide, and 0.05 g of I_2 in carbon tetrachloride (20 ml) was refluxed for 3 hr in darkness. The mixture was cooled, filtered, and evaporated to leave 1.42 g (100%) of dibromopyrone **16** as a yellow oil. The oil crystallized on standing: mp 53–60°; ir (Nujol) 1790, 1690, and 1660 cm^{-1}; nmr ($CDCl_3$) δ 2.3 (d, 3, J = 0.9 Hz, 6-CH_3) and 5.7 ppm (q, 1, J = 0.9 Hz, 5-**H**); mass spectrum (direct inlet, 70 eV) m/e 286, 284, and 282. Attempted recrystallization caused extensive decomposition. Slow reversion to **11** occurred upon standing.

Registry No.—**1**, 771-03-9; **4**, 23668-02-2; **5**, 23668-03-3; **6**, 23668-04-4; **8**, 23668-05-5; **9**, 23754-53-2; **10**, 23668-06-6; **11**, 23668-07-7; **13**, 23668-08-8; **14**, 23754-54-3; **15**, 670-35-9; **16**, 23668-10-2.

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