Syntheses of Squaric Acid, Its Monoorthoesters, and Related Derivatives via [2 + 2] Cycloadditions of Tetraalkoxyethylenes with Heterosubstituted Ketenes[1]

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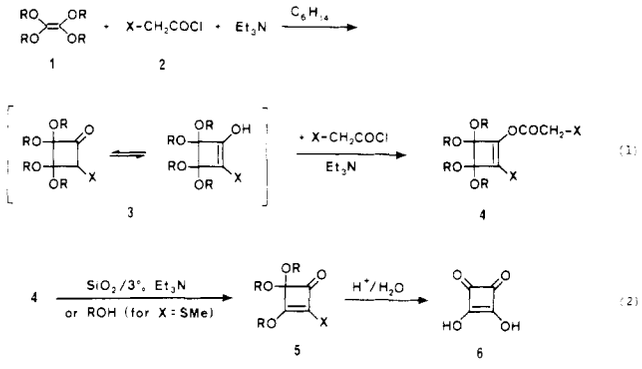
Efficient syntheses of squaric acid are reported. The synthetic approach begins with the [2 + 2] cycloaddition reaction of tetraalkoxyethylenes with oxyketenes, which are produced in situ by triethylamine-promoted dehydrohalogenation of the corresponding acyl chlorides. The intermediately formed cyclobutanones undergo rapid enolization followed by esterification with the second equivalent of acid chloride to give the key compounds, the cyclobutenol esters **4a–c**. Displacement-induced fragmentation of these esters, promoted by SiO_2/triethylamine or basic Al_2O_3, yields smoothly the hitherto unknown monoorthoesters of squaric acid (**5a–c**). The acid hydrolyses of the cyclobutenol esters **4a,c** and the orthoesters **5b,c**, as well as the cyclobutenol esters **4d–f** formed by similar [2 + 2] cycloadditions involving acetoxyketene and chloroketene, afford squaric acid (**6**) in high yields. When tetraalkoxyethylenes are reacted with in situ generated methylthioketene and phthalimidoketene, the corresponding cyclobutenol esters **4g** and **4h** are formed. However, **4g** and **4h** behave differently in subsequent reactions: **4g** gives on acid hydrolysis the monomethyl thioester of squaric acid as the final product; **4h** is stable toward SiO_2/triethylamine, whereas attempted ethanolysis leads to ring-opened products **11** and **12**.

Squaric acid (**6**) is a deceptively simple organic molecule which has captured the imagination of chemists since its discovery by Cohen, Lacher, and Park in 1959.[3,4] Since then, many procedures have become available for the synthesis of **6**. With one very recent exception,[2] however, these include at least one laborious synthetic step, e.g., an autoclave reaction with fluorinated olefins,[3,5–7] the hydrolysis of halogenated cyclobutenes at elevated temperatures by concentrated acids,[5,6,8–11] a low-yield photochemical [2 + 2] cycloaddition,[2,12] or the electrochemical cyclotetramerization of carbon monoxide,[13] or involve a curious starting material, di-*tert*-butoxyethyne.[14] As part of a program directed toward a study of biologically active derivatives of hydroxycyclobutenediones,[15] we looked for an easy new preparation of **6**. In this paper we describe syntheses of some hitherto unknown derivatives of squaric acid, especially its monoorthoesters, and their smooth hydrolyses to **6**. In addition, some related S and N derivatives will be described.

Results and Discussion

An interesting approach to highly oxidized cyclobutenes, discovered by R. W. Hoffmann,[16] involves thermal [2 + 2] cycloaddition of tetramethoxyethylene (**1**, R = CH_3) to electron deficient olefins and cumulenes followed by hydrolysis of the resulting tetramethoxycyclobutanes. By application of this procedure to [2 + 2] cycloadducts of tetraalkoxyethylenes with gaseous ketene,[2,17] as well as with in situ prepared alkyl-, vinyl-, and arylketenes, we recently made readily available a large number of the correspondingly substituted 1-hydroxy-1-cyclobutene-3,4-diones.[15] As a continuation of our work in this area, we also studied the [2 + 2] cycloadditions of the now readily available tetraalkoxyethylenes[2,18] with ketenes bearing substituents which would further raise the oxidation level of the resulting cyclobutanones. For this purpose, we chose methoxyketene,[19] ethoxyketene,[20] acetoxyketene,[21] chloroketene,[21] methylthioketene,[22] and phthalimidoketene,[23] which were produced in situ by dehydrochlorination of the corresponding acid chlorides with triethylamine.

Surprisingly, when tetramethoxyethylene (**1**, R = CH_3) was allowed to react with 1 equiv of methoxyacetyl chloride (**2**, X = OCH_3) in refluxing hexane in the presence of 1.1 equiv of triethylamine, no cyclobutanone **3** (R = CH_3, X = OCH_3) was formed. Under these conditions, 50–55% of **1** (R = CH_3) was unreacted and cyclobutenol ester **4a**, bp 110 °C (0.015 mm), was isolated in 40% yield. **4a** arises by esterification of the enol form of the primarily formed cyclobutanone **3** (R = CH_3, X = OCH_3), thereby consuming another equivalent of acid chloride **2** (X = OCH_3). The facile formation of **4a** is understandable in light of the very rapid base-catalyzed enolization of cyclobutanones.[24] When 2.1–2.2 equiv of the oxysubstituted acid chlorides **2** were used, the cyclobutenol esters **4a–c** and the cyclobutene-1,2-diol diester **4d** were formed in comparable yields (Table I), and tetraalkoxyethylenes **1** were no longer present in the reaction mixtures.



Careful NMR analysis of crude **4a** showed the presence of a minor component (less than 5%), whose structure was assigned as 2,3,4,4-tetramethoxy-2-cyclobuten-1-one (**5a**) on the basis of its spectral properties (e.g., δ 4.11, characteristic for a CH_3O group in position 3 of 3-methoxy-2-cyclobuten-1-ones[2,25]). Spontaneous elimination of alcohol such as **3a** → **5a** is a known side reaction of 3-alkoxy substituted cyclobutanones.[17] The formation of **5a** became a predominant, preparatively useful reaction when an ether solution of **4a** was treated with a 15-fold weight excess of silica gel/3% triethylamine system[2] or basic alumina,[26] thus providing **5a** in 80% yield (Table II). Although no extensive optimization has been attempted, **5b** and **5c** were prepared in good yields after similar treatment with the SiO_2/Et_3N system (eq 2). The tetraalkoxycyclobutenones **5a** and **5c** represent the first *monoorthoesters of squaric acid*, and **5b** is the first mixed monoorthoester of squaric acid known so far.[27] Under identical experimental conditions, the cyclobutene-1,2-diol diester **4d** underwent twofold displacement-induced fragmentation, initiated by cleavage of an ester group by some external nucleophilic species (eq 3). As a result, dimethyl squarate (**8**) was formed, presumably via intermediate cyclobutenone enol ester **7**.

Inspection of the data in Table I reveals that the outcome

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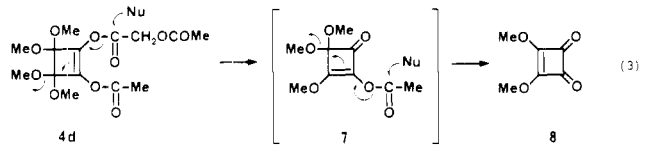
Table I. Tetraalkoxycyclobutenol Esters 4 from Reaction of Tetraalkoxyethylenes [$(RO)_2C{=}C(OR)_2$] with Monosubstituted Ketenes (XHC=C=O), Produced In Situ from Ketene Precursors XCH_2COCl [a]

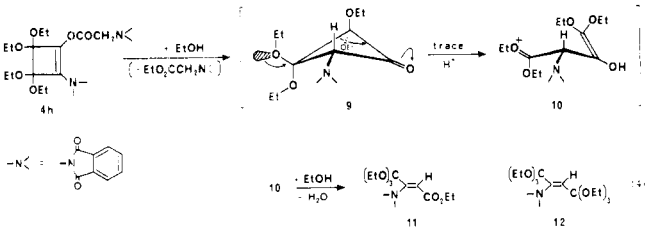
compd	R	X	yield, %	bp (mm), °C
4a	CH_3	OCH_3	69	110 (0.015)
4b	C_4H_9	OCH_3	86	oil[b]
4c	C_2H_5	OC_2H_5	82	125 (0.01)
4d	CH_3	$OCOCH_3$	82	oil[b]
4e	CH_3	Cl	*b*	oil[b]
4f	C_2H_5	Cl	*b*	oil[b]
4g	C_2H_5	SCH_3	84[c]	oil[b]
4h	C_2H_5	phthalimido	39	95–105[d]

[a] See eq 1 for reaction. [b] See Experimental Section. [c] Consists of 66% **4g** and 18% **5g**. [d] Melting point (dec).



of cycloadditions of methylthioketene and chloroketene to tetraalkoxyolefins was slightly different from that of oxyketenes. The content of cyclobutenones **5** in the crude reaction mixtures was considerably higher: 18% of **5g** in the crude **4g** and about 50% of **5e,f** in the crude **4e** and **4f**, respectively, as assessed by IR. In the two latter cases, the thermal and hydrolytic instability of both **4e,f** and **5e,f** renders their separation and full characterization impossible.

The crystalline cyclobutenol ester **4h**, formed from phthalimidoketene, was surprisingly inert toward SiO_2/Et_3N- or Al_2O_3-induced fragmentation, which would lead to **5** (X = phthalimido). On the other hand, if dry ethanol was used for ethanolysis of the enol ester **4h**, no cyclobutenone was formed, but an unexpected ring-opening reaction proceeded smoothly (eq 4). Two crystalline orthoester derivatives **11** and **12** were

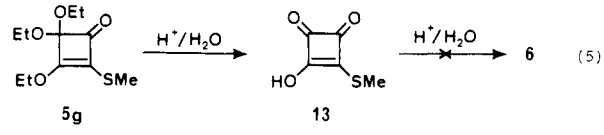


isolated in 33 and 56% yield, respectively. A plausible mechanism for their formation involves the ethanolysis of **4h** to cyclobutanone **9**, followed by acid-assisted heterolytic ring opening to **10**. The latter event, which resembles the Grob fragmentation reaction,[28] was studied in detail in connection with the acid-catalyzed hydrolysis of tetraalkoxycyclobutanones to the mycotoxin moniliformin.[2] The tertiary dialkoxycarbenium end of **10** gives with ethanol an orthoester group.[29] The electron-rich double bond of the intermediate orthoester thus formed is protonated by ethanol, thus producing another dialkoxycarbenium ion, which subsequently either adds ethanol to form the second terminal orthoester group or dealkylates to an ester group.[29] After elimination of a molecule of water, **11** and **12**, respectively, are formed.

The *Z* configuration of **11** follows from its ^{13}C NMR spectrum. The coupling constant $^3J_{C,H}$ between C(4) and H–C(2) of less than 2 Hz indicates their mutual cis position because for the trans position a value of 9–10 Hz would be expected in comparison with 3-N-substituted (*Z*)-butenoic acid derivatives.[30] By analogy, **12** is tentatively given the *Z* configuration; however, no definitive assignment to either isomer follows from NMR data.

The cyclobutenol esters **4a,c** and the cyclobutenediol diester **4d**, as well as the monorthoesters **5b,c**, were found to be ideal precursors of squaric acid (**6**). Simple hydrolysis with 18% hydrochloric acid at 100 °C cleanly produced **6** in yields of 67–89%. In the case of chloro-substituted cyclobutenol esters **4e** and **4f**, however, higher yields of **6** were achieved using concentrated sulfuric acid. Results of hydrolysis experiments are summarized in Table II.

In contrast to the above mentioned monoorthoesters **5b,c**, the mixed *O,S*-orthoester **5g** afforded, under similar hydro-



lytic conditions (18% HCl, 100 °C, 2 h), the monomethyl thioester of squaric acid (**13**), which was surprisingly resistant to further hydrolysis. For example, after a 2-day hydrolysis of **5g** with 13% HCl at 100 °C, only 6% of **6** was formed along with 45% of **13**. Similarly, the hydrolysis of crude **4g** gave only **13** in the same yield. It appears therefore that the [2 + 2] cycloaddition of an alkylthio- or arylthio-substituted ketene followed by acid hydrolysis of the resulting products constitutes an easy method for synthesis of the hitherto unknown monothioesters of squaric acid.

Experimental Section

3,3,4,4-Tetraalkoxycyclobutenol Esters 4 from Tetraalkoxyethylenes 1 and Ketenes 2, Formed In Situ from Acid Chlorides.

Table II. Monoorthoesters of Squaric Acid and Related Cyclobutenones. Yields of Squaric Acid Formed from Them

$$4 \xrightarrow{SiO_2/Et_3N} 5 \xrightarrow{H^+/H_2O} 6$$

compd	R	X	compd	yield, %	bp (mm), °C	yield of **6**, %
4a	CH_3	OCH_3	**5a**	80	55–61 (0.1)[a]	89[b]
4b	C_4H_9	OCH_3	**5b**	72	105–110 (0.005)[a]	67
4c	C_2H_5	OC_2H_5	**5c**	85	oil[c]	88[d]
4d	CH_3	$OCOCH_3$	**8**	25	(55.5–56[e])	74[b]
4e	CH_3	Cl	**5e**	20[c]	oil[c]	64[b]
4f	C_2H_5	Cl	**5f**	*c,f*		58[b]
4g	C_2H_5	SCH_3	**5g**[g]	73	oil[c]	(61)[h]
4h	C_2H_5	phthalimido	*i*			

[a] Boiling point in Kugelrohr. [b] In this experiment, the corresponding **4** was directly hydrolyzed to **6**. [c] See Experimental Section. [d] 87% yield if **4c** was hydrolyzed. [e] Melting point. [f] Isolation was not possible due to instability of primarily formed **4f** and **5f**; **5e** and **5f** were present already in the crude reaction mixtures. [g] After ethanolysis instead of SiO_2/Et_3N treatment. [h] **13**, monomethyl thioester of **6**. [i] **4h** stayed unchanged after treatment with the SiO_2/Et_3N system.

General Procedure. 1-(Methoxyacetoxy)-2,3,3,4,4-pentamethoxy-1-cyclobutene (4a). Tetramethoxyethylene[2,18] (14.8 g, 0.1 mol) and triethylamine (30.5 mL, 0.22 mol) in 180 mL of hexane were refluxed under nitrogen. Methoxyacetyl chloride (22.8 g, 0.21 mol) in 40 mL of hexane was added dropwise over 30 min. This was refluxed for another 4 h and stirred at room temperature for 19 h. The reaction mixture was filtered, and the filtrate was concentrated to give 24.3 g of a cognac-brown oil which on distillation provided 20.15 g (69%) of cyclobutenol ester **4a:** bp 110 °C (0.015 mm); IR (neat) 1786, 1730, 1449, 1325, 1295, 1199, 1099, 983 cm^{-1}; NMR ($CDCl_3$) δ 3.44, 3.49, 3.52 (three s, 15 H, five OCH_3), 3.84 [s, 3 H, OCH_3-C(2)]), 4.18 (s, 2 H, $-COCH_2O-$). Anal. Calcd for $C_{12}H_{20}O_8$: C, 49.13; H, 6.90; O, 43.79. Found: C, 49.00; H, 5.94; O, 43.99.

1-(Methoxyacetoxy)-2-methoxy-3,3,4,4-butoxy-1-cyclobutene (4b). Similarly, from 0.1 mol of tetrabutoxyethylene (**1c**)[2] was obtained an oil, which, after being placed under vacuum (0.5 mm/80 °C) for 6 h, provided 19.8 g (86%) of **4b** (NMR purity was better than 95%): IR (neat) 1783, 1730, 1292, 1200 cm^{-1}; NMR ($CDCl_3$) δ 0.98 (br t, 12 H, four CH_3), 1.1–1.9 (m, 16 H, four $-CH_2CH_2-$), 3.4–3.9 (m, 8 H, four $-OCH_2-$), 3.48 (s, 3 H, $-OCH_3$), 3.83 (s, 2 H, $-COCH_2O-$), 4.16 [s, 3 H, OCH_3-C(2)]). Anal. Calcd for $C_{24}H_{44}O_8$: C, 62.58; H, 9.63; O, 27.79. Found: C, 63.30; H, 10.09; O, 26.91.

1-(Ethoxyacetoxy)-2,3,3,4,4-pentaethoxy-1-cyclobutene (4c). From 0.1 mol of tetraethoxyethylene (**1b**)[2,18] and 0.22 mol of ethoxyacetyl chloride was obtained **4c** (30.8 g, 82%) as a colorless liquid: bp 120–125 °C (0.01 mm); IR (neat) 1785, 1727, 1285 cm^{-1}; NMR ($CDCl_3$) δ 1.1–1.5 (m, 18 H, six $-CH_3$), 3.45–3.95 (m, 10 H, five $-OCH_2-$), 4.12 [q, 2 H, $(-OCH_2-)$-C(2)], 4.18 (s, 2 H, $-COCH_2O-$). Anal. Calcd for $C_{18}H_{32}O_8$: C, 57.43; H, 8.57; O, 34.00. Found: C, 56.88; H, 8.52; O, 34.30.

1-(Acetoxyacetoxy)-2-acetoxy-3,3,4,4-tetramethoxy-1-cyclobutene (4d). From 0.138 mol of tetramethoxyethylene (**1a**) and 0.3 mol of acetoxyacetyl chloride was obtained an oil which, when placed under vacuum (0.1 mm/60 °C) for 4 h, gave 38.9 g (82%) of crude **4d** (purity assessed from NMR was about 94%): IR (neat) 1786, 1757, 1724, 1085 cm^{-1}; NMR ($CDCl_3$) δ 2.18, 2.21 (two s, 6 H, two $-COCH_3$), 3.50 (s, 12 H, four $-OCH_3$), 4.73 (s, 2 H, $-COCH_2O-$).

1-(Chloroacetoxy)-2-chloro-3,3,4,4-tetramethoxy-1-cyclobutene (4e) and 2-Chloro-3,4,4-trimethoxycyclobut-2-en-1-one (5e). From 0.2 mol of **1a** and 0.42 mol of chloroacetyl chloride at 0–5 °C was obtained 60.8 g of an oil which consisted of 80 ± 5% **4e** [IR (neat) 1751 (enolate C=O) cm^{-1}; NMR ($CDCl_3$) δ 4.18 (s, 2 H, $-OCOCH_2Cl$)] and 12 ± 3% **5e** [IR (neat) 1792 (C=O), 1639 (strong, C=C) cm^{-1}; NMR ($CDCl_3$) δ 4.27 (s, 3 H, OCH_3-C(3))] besides a small amount of unidentified byproducts. The mixture was too unstable to allow further purification. Very quick column chromatography on silica gel (hexane/diethyl ether, 4:1) of a 0.5-g sample afforded only 0.1 g of pure **5e:** IR (neat) 1792, 1639, 1449, 1333,1124, 1087, 801, 794 cm^{-1}; NMR ($CDCl_3$) δ 3.52 [s, 6 H, $(-OCH_3)_2$-C(4)], 4.27 [s, 3 H, $-OCH_3$-C(3)].

1-(Chloroacetoxy)-2-chloro-3,3,4,4-tetraethoxy-1-cyclobutene (4f) and 2-Chloro-3,4,4-triethoxycyclobut-2-en-1-one (5f). From 0.2 mol of **1b** and 0.42 mol of freshly distilled chloroacetyl chloride at 0 °C was obtained 62 g of a brown oil which consisted of **4f** [IR (neat) 1751 (enolate C=O) cm^{-1}] and **5f** [IR (neat) 1789 (C=O), 1637 (C=C) cm^{-1}]. The thermal and hydrolytic instability of this crude reaction mixture renders further purification and separation impossible.

1-[(Methylthio)acetoxy]-2-(thiomethyl)-3,3,4,4-tetraethoxy-1-cyclobutene (4g) and 2-(Methylthio)-3,4,4-triethoxycyclobut-2-en-1-one (5g). From 0.1 mol of **1b** and 0.21 mol of (methylthio)acetyl chloride[22] was obtained 35.2 g of an oil consisting of 66% **4g,** 18% **5g,** about 13% ethyl (methylthio)acetate, and a small amount of unidentified byproducts. Assignment of NMR ($CDCl_3$) signals for **4g:** δ 1.28 (t, J = 8.5 Hz, 12 H, four CH_3), 2.33, 2.42 (two s, 6 H, two SCH_3), 3.27 (s, 2 H, $-COCH_2S-$), 3.5–3.9 (m, 8 H, four $-OCH_2-$). For **5g:** δ 1.26 (t, J = 8.5 Hz, 6 H, two CH_3), 1.48 (t, 3 H, CH_3), 2.55 (s, 3 H, SCH_3), 3.5–3.9 [m, 4 H, $(-OCH_2)_2$-C(4)], 4.5 [q, J = 8.5 Hz, 2 H, $(-OCH_2-)$-C(3)]. For ethyl (methylthio)acetate: δ 2.21 (s, 3 H, SCH_3), 3.18 (s, 2 H, $-SCH_2-$), 4.19 (q, 2 H, $-OCH_2-$).

1-(Phthalimidoacetoxy)-2-phthalimido-3,3,4,4-tetraethoxy-1-cyclobutene (4h). From 0.1 mol of **1b** and 0.2 mol of phthalimidoacetyl chloride was obtained 62.9 g of an oil which, after addition of 180 mL of diethyl ether, yielded 27 g of dark yellow crystals. Recrystallization from ether afforded 22.5 g (39%) of **4h:** mp 95–105 °C dec; IR (KBr) 1780, 1725, 1653, 1392, 1247, 1118, 1033, 886, 718 cm^{-1}; NMR ($CDCl_3$) δ 0.8–1.5 (m, 12 H, all CH_3), 3.5–4.2 (m, 8 H, all $-OCH_2-$), 4.47 (s, 2 H, $-COCH_2N$), 7.6–8.0 (m, 8 aromatic H). Anal. Calcd for $C_{30}H_{30}N_2O_{10}$: C, 62.28; H, 5.23; N, 4.84; O, 27.65. Found: C, 62.23; H, 5.27; N, 4.79; O, 27.87.

2,3,4,4-Tetraalkoxycyclobutenones 5 ("Monoorthoesters" of Squaric Acid) from Cyclobutenol Esters 4. General Procedure. 2,3,4,4-Tetramethoxycyclobut-2-en-1-one (5a). Alumina (50 g) or a mixture of silica gel (60 g) and triethylamine (2 mL) was stirred in 100 mL of diethyl ether at room temperature under nitrogen. 1-(Methoxyacetoxy)-2,3,3,4,4-pentamethoxy-1-cyclobutene (**4a,** 6.1 g, 0.021 mol) in 20 mL of diethyl ether was added dropwise over 20 min. The heterogeneous mixture was stirred for another 2 h. The silica gel (or alumina) was then removed by filtration and washed thoroughly with diethyl ether. The filtrate was concentrated and placed under vacuum (1 mm) for 2 h. The resultant oil was distilled, giving 2.9 g (80%) of **5a** as a colorless liquid: bp 55–60 °C (0.1 mm; Kugelrohr); IR (neat) 1786 (C=O), 1645 (strong, C=C), 1471, 1350, 1073, 1036, 861 cm^{-1}; UV (MeOH) 249, 294 sh nm (log ϵ 4.05, 2.32); NMR ($CDCl_3$) δ 3.51 [s, 6 H, $(-OCH_3)_2$-C(4)], 4.0, 4.11 [two s, 6 H, $-OCH_3$-C(2) and $-OCH_3$-C(3)]. Anal. Calcd for $C_8H_{12}O_5$: C, 51.06; H, 6.43; O, 42.51. Found: C, 50.77; H, 6.54; O, 42.87.

2-Methoxy-3,4,4-tributoxycyclobut-2-en-1-one (5b). Similarly, from 9.21 g (0.02 mol) of **4b** was obtained 6.3 g (72%) of **5b** as a colorless viscous liquid: bp 105–10 °C (0.005 mm); IR (neat) 1776 (C=O), 1653 (C=C), 1460, 1257, 1117, 1076 cm^{-1}; UV (C_4H_9OH) 250 nm (log ϵ 4.0); NMR ($CDCl_3$) δ 0.98 (br t, 9 H, three CH_3), 1.2–1.9 (m, 12 H, three $-CH_2CH_2-$), 3.6 [t, 4 H, $(-OCH_2-)_2$-C(4)], 4.0 (s, 3 H, OCH_3), 4.38 [t, 2 H, $(-OCH_2-)$-C(3)]. Anal. Calcd for $C_{17}H_{30}O_5$: C, 64.94; H, 9.62; O, 25.44. Found: C, 64.62; H, 10.04; O, 24.67.

2,3,4,4-Tetraethoxycyclobut-2-en-1-one (5c). From 7.52 g (0.02 mol) of **4c** was obtained 4.15 g (85%) of **5c** as a colorless liquid: IR (neat) 1779, 1642, 1332 cm^{-1}; UV (EtOH) 251, 296 sh nm (log ϵ 4.09, 2.42); NMR ($CDCl_3$) δ 1.27, 1.34, 1.45 (three t, 6 H, 3 H, 3 H, four CH_3), 3.8 [q, 4 H, $(-OCH_2)_2$-C(4)], 4.35, 4.46 [two q, 2 H, 2 H, $(-OCH_2-)$-C(2) and $(-OCH_2-)$-C(3)]. Anal. Calcd for $C_{12}H_{20}O_5$: C, 59.00; H, 8.26, O, 32.75. Found: C, 58.64; H, 8.22; O, 32.70.

2-(Methylthio)-3,4,4-triethoxycyclobut-2-en-1-one (5g). A solution of 10 g of crude **4g,** prepared as described above, in 250 mL of dry ethanol was stirred at 60 °C for 2 h. After the alcohol was evaporated, the residue was subjected to column chromatography on silica gel. Elution with hexane/diethyl ether 4:1 gave 2 g of ethyl (methylthio)acetate and 5.4 g (73%) of **5g** as a colorless liquid: IR (neat) 1774, 1599, 1318 cm^{-1}; UV (EtOH) 264 nm (log ϵ 3.82); NMR, see above for **4g.** Anal. Calcd for $C_{11}H_{18}O_4S$: C, 53.64; H, 7.37; S, 13.02. Found: C, 53.59; H, 7.42; S, 13.29.

Hydrolysis of 4a, 4c, 4d, 5b, and 5c to Squaric Acid (6). A 0.05-mol amount of either the cyclobutenol ester **4** or the corresponding cyclobutenone **5** was added to 200 mL of 18% hydrochloric acid. The resulting emulsion was rapidly stirred at 100 °C. The first white crystals of squaric acid appeared after 3–4 min. After 15 min, the mixture was cooled to 0 °C and the precipitated **6** was collected by filtration. The filtrate was evaporated, and the oily crystalline residue was washed with toluene/acetonitrile, yielding another portion of squaric acid (**6**). Its identity was proven by comparison with an authentic sample.[33] The individual yields of **6** are given in Table II.

Hydrolysis of 4e and 4f to Squaric acid (6). Crude **4e** or **4f,** prepared from 0.2 mol of the corresponding tetraalkoxyethylene and containing some **5e** and **5f,** respectively (see above), was added to 120 mL of concentrated sulfuric acid. The two-phase mixture was stirred at 100 °C for 90 min. The deeply colored, now one-phase reaction mixture was poured into 300 mL of ice water. After 2 h, the precipitate was separated by filtration, washed with cyclohexane, and dissolved in 180 mL of boiling water. The solution was treated with charcoal and filtered. The filtrate was concentrated to 30 mL and cooled to 0 °C. After 5 h, 14.6 and 13.2 g (64 and 58%, respectively, calculated on 0.2 mol of the corresponding tetraalkoxyethylene) of **6** as white crystals were obtained, which were identical in every respect with an authentic sample of **6.**[33]

1,2-Dimethoxycyclobut-1-ene-3,4-dione (Dimethyl Squarate) (8). Treatment of 6.96 g (0.02 mol) of crude **4d** with silica gel/3% Et_3N according to the general procedure for conversion of, e.g., **4a** to **5a** (see above) yielded 1.4 g (50%) of **8:** mp 55.5–56 °C (methanol/hexane) (lit. mp 56[31] and 52–53 °C[32]); NMR ($CDCl_3$) δ 4.36 (s, 6 H, two OCH_3); indistinguishable from a sample of the authentic material (IR, TLC in two solvent systems) prepared from squaric acid and methanol.[31]

Ethyl 3-Phthalimido-4,4,4-triethoxy-(*Z*)-2-butenoate (11) and 1,1,1,4,4,4-Hexaethoxy-2-phthalimido-(*Z*)-2-butene (12). A solution of 11.6 g (0.02 mol) of **4h** in 300 mL of dry ethanol was kept at room temperature for 24 h. After the alcohol was evaporated, the residue was subjected to column chromatography. Elution with hexane/diethyl ether (3:1) gave first 5.2 g (56%) of **12:** mp 132–133 °C (diethyl ether); IR ($CHCl_3$) 1726, 1616, 1388, 1297, 1085, 890 cm^{-1};

^{1}H NMR ($CDCl_3$) δ 0.99, 1.23 (two t, 9 H, 9 H, all CH_3), 3.47, 3.71 (two q, 6 H, 6 H, all $-OCH_2-$), 6.26 [s, 1 H, H-C(3)], 7.6–7.9 (m, 4 aromatic H); ^{13}C NMR ($CDCl_3$) δ 14.63, 14.75 (CH_3), 57.81, 58.20 (CH_2), 111.74, 112.43 [C(1) and C(4)], 123.08, 132.82, 133.16, 133.62, 134.32 [all aromatic C, C(2), and C(3)], 167.62 (C=O). Anal. Calcd for $C_{24}H_{35}NO_8$: C, 61.92; H, 7.58; N, 3.09; O, 27.49. Found: C, 62.02; H, 7.57; N, 3.20; O, 27.23.

In the second fraction was found 2.6 g (33%) of **11**: mp 78.5–79.5 °C (hexane); IR ($CHCl_3$) 1730, 1390, 1298, 1085, 887, 715 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 1.11, 1.23 (two t, 3 H, 9 H, all CH_3), 3.68 [q, 6 H, $(-OCH_2-)_3$-C(4)], 4.07 (q, 2 H, ester $-OCH_2-$), 6.72 [s, 1 H, H-C(2)], 7.6–8.0 (m, 4 aromatic H); ^{13}C NMR ($CDCl_3$) δ 13.84, 14.69 (CH_3), 58.49, 60.94 (CH_2), 111.35 [$^3J_{C,H}$ = 2 Hz, C(6)], 125.07 [$^1J_{C,H}$ = 167.2 Hz, C(2)], 123.48, 132.42, 134.01 (all aromatic C), 141.61 [$^2J_{C,H}$ = 1.5 Hz (d), C(3)], 163.12 [$^2J_{C,H}$ = 1.1 Hz (d), $^3J_{C,H}$ = 2.9 Hz (t), C(1)], 166.65 (C=O). Anal. Calcd for $C_{20}H_{25}NO_7$: C, 61.37; H, 6.44; N, 3.58; O, 28.61. Found: C, 61.29; H, 6.36; N, 3.49; O, 28.83.

1-Hydroxy-2-(methylthio)cyclobut-1-ene-3,4-dione (13). A solution of 3.7 g (0.015 mol) of **5g** in 50 mL of ethanol and 40 mL of 18% hydrochloric acid was stirred at 100 °C. After 2 h, evaporation yielded an oily crystalline residue which on recrystallization (diethyl ether) gave 1.3 g (61%) of pure **13**: mp 150–152 °C; IR ($CHCl_3$) 2500 (br d, OH), 1785, 1698, 1608, 1389, 1282, 1124, 794; NMR (Me_2SO-d_6) δ 2.80 (s, 3 H, SCH_3),[34] 13.32 (s, 1 H, OH); MS, *m/e* 144 (M^+, base peak), 116 ($M^+ - CO$), 88 ($M^+ - O{=}C{=}C{=}O$), 73, 69, 48. The similar hydrolysis of crude **4g** afforded **13** in the same yield.

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Registry No.—**1a,** 1069-12-1; **1b,** 40923-93-1; **1c,** 40923-96-4; **2** (X = OMe), 38870-89-2; (X = OEt), 14077-58-8; **2** (X = OAc), 13831-31-7; **2** (X = Cl), 79-04-9; **2** (X = SMe), 35928-65-5; **2** (X = 2-phthalimido), 6780-38-7; **4a,** 67543-97-9; **4b,** 67543-99-1; **4c,** 67543-95-7; **4d,** 67544-05-2; **4e,** 67544-03-0; **4f,** 67544-01-8; **4g,** 69177-73-7; **4h,** 69177-74-8; **5a,** 67543-98-0; **5b,** 67544-00-7; **5c,** 67543-96-8; **5e,** 67544-04-1; **5f,** 67544-02-9; **5g,** 69177-75-9; **6,** 2892-51-5; **8,** 5222-73-1; **11,** 69177-76-0; **12,** 69177-77-1; **13,** 69177-78-2; methoxyketene, 54276-52-7; ethoxyketene, 28288-35-9; acetoxyketene, 55778-27-3; chloroketene, 29804-89-5; methylthioketene, 58216-36-7; phthalimidoketene, 69177-79-3.

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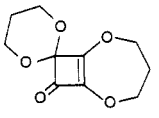

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