Cycloadditions of 6*H*-1,3,4-oxadiazin-6-ones (4,5-diaza-α-pyrones). Part 16.[1] 4-Substituted and 4,5-disubstituted methyl 3-phenyl-α-pyrone-6-carboxylates from γ-oxoketenes *via* α,δ-dibromo-δ-lactones

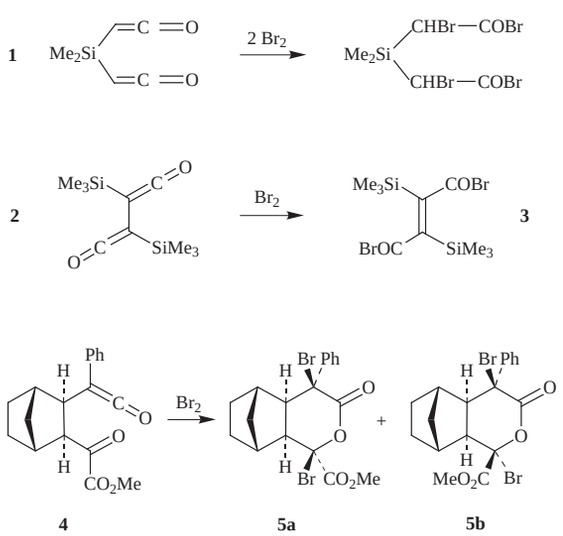
Thomas T. Tidwell,[a] Frank Sammtleben[b] and Manfred Christl*,[b]

[a] *Department of Chemistry, University of Toronto, Toronto, Ontario, Canada M5S 3H6*
[b] *Institut für Organische Chemie, Universität Würzburg, Am Hubland, D-97074 Würzburg, Germany*

The addition of bromine to the γ-oxoketenes 4, 10 and 22 and the elimination of two equivalents of hydrogen bromide from the resulting α,δ-dibromo-δ-lactones 5, 12 and 23 to give the α-pyrones 7, 19 and 20, respectively, are described. Since the isolation of neither 4, 10 and 22 nor 5, 12 and 23 proved necessary, the α-pyrones have been prepared in one-pot procedures from methyl 6-oxo-5-phenyl-6*H*-1,3,4-oxadiazine-2-carboxylate 6.

Introduction

Many γ-oxoketenes are readily accessible by reaction of 6-oxo-6*H*-1,3,4-oxadiazines with alkenes.[2] They undergo a variety of reactions, in most of which a co-operation of the ketene and ketone functionalities has been observed.[2] In particular, the addition of hydrogen chloride gives rise to δ-chloro-δ-lactones.[3] In a preparative and kinetic investigation of the addition of bromine to mono- and bis-ketenes, the behaviour of the γ-oxoketene **4** was studied as well.[4] Previously, only a few reactions of ketenes with halogens have been examined, and these yield α-halocarboxylic acid halides.[5] Whereas dimethyl(phenyl)-silylketene and 3,3-dimethyl-3-silapenta-1,4-diene-1,5-dione **1** react entirely analogously, 2,3-bis(trimethylsilyl)buta-1,3-diene-1,4-dione **2** and γ-oxoketene **4** gave rise to fumaric acid dibromide **3** and the α,δ-dibromo-δ-lactones **5a**,**b**, respectively, the configurations of which were elucidated by X-ray structure analyses (Scheme 1).[4]



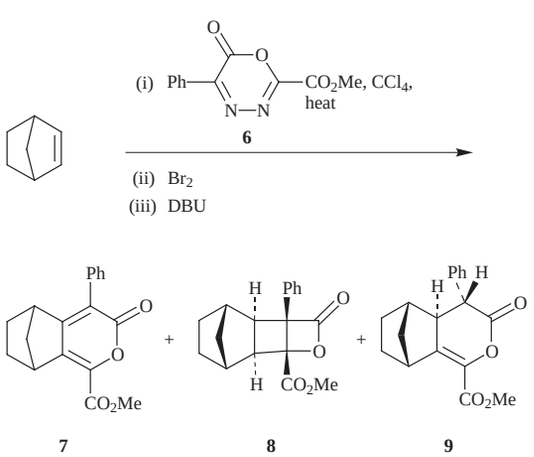
Scheme 1

The kinetic measurements disclosed that the addition of bromine to **2** in 1,2-dichloroethane proceeds as a second-order reaction, first order in bromine. In contrast, all other ketenes examined, including **4**, follow third-order kinetics, second order in bromine.[4] The addition of bromine to ordinary alkenes in chlorinated hydrocarbons are also typically third-order reactions of this type.[6]

Herein we describe the action of bromine on two further γ-oxoketenes leading to products analogous to **5**, and the subsequent elimination of two equivalents of hydrogen bromide from these, giving rise to α-pyrones. These α-pyrones have been prepared in one-pot procedures, starting from methyl 6-oxo-5-phenyl-6*H*-1,3,4-oxadiazine-2-carboxylate **6**, which is readily accessible from phenylglyoxylic acid and oxalic acid methyl ester hydrazide.[7a] This reaction sequence may prove useful for the synthesis of α-pyrones of this type.

Results and discussion

The tetrasubstituted α-pyrone **7** was obtained as follows: (i) heating of a solution of norbornene and **6** in tetrachloromethane until **6** was consumed completely, (ii) addition of bromine to the resulting solution of γ-oxoketene **4** and (iii) treatment of the solution of the α,δ-dibromo-δ-lactones **5** with 1,8-diazabicyclo[5.4.0]undec-7-ene (DBU). Purification of the crude product afforded **7** in 35% yield and small amounts of two compounds characterised previously, *i.e.* the β-lactone **8**[7] and the dihydro-α-pyrone **9** (Scheme 2).[3b]

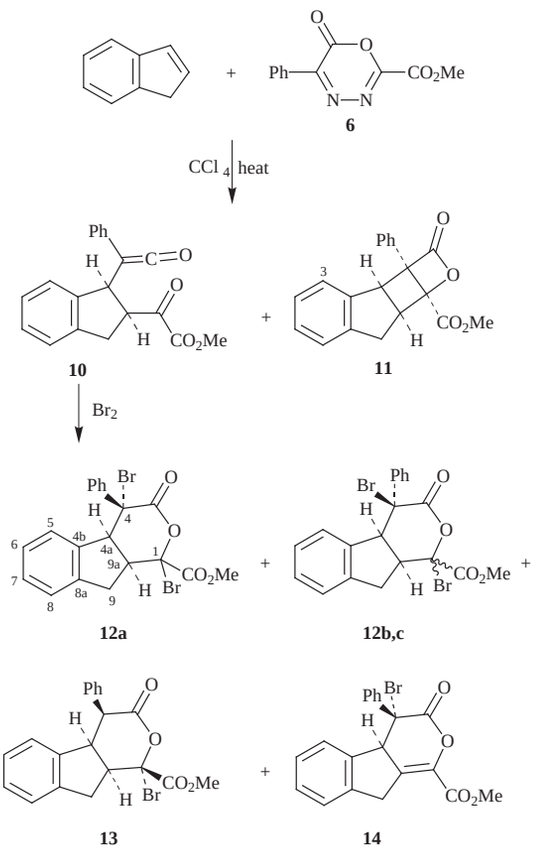


Scheme 2

The β-lactone **8** is an unavoidable byproduct of the synthesis of **4** from **6** and norbornene,[7] while **9** can be prepared from **4** by treatment with triflic acid.[3b] It is apparent that α,δ-dibromo-

δ-lactones such as **5** are only of limited persistance, a phenomenon that is more obvious in the case of the corresponding compounds derived from indene (**12**, see below). If a spontaneous elimination of hydrogen bromide occurs while γ-oxoketene **4** is still present, the acid may catalyse the isomerisation of **4** to **9**.

As described previously,[3a] indene was converted into the γ-oxoketene **10** on heating in the presence of oxadiazinone **6**. The solution of **10** and β-lactone **11** in tetrachloromethane thus obtained was exposed to bromine, and chromatography of the crude product gave the α,δ-dibromo-δ-lactones **12a**,**b**,**c**, the β-lactone **11**, the δ-bromo-δ-lactone **13** and the bromodihydro-α-pyrone **14** in the ratio of 2 : 11 : 14 : 15 : 14 : 13 (Scheme 3).



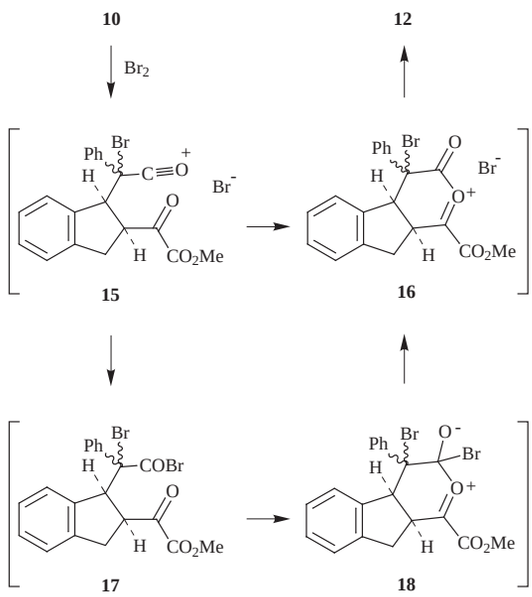
Scheme 3

Since the compounds **12** proved to be labile, probably because of spontaneous loss of HBr, they have been characterised by their ^{1}H NMR spectra only. The configuration of C-4 is based on the relative positions of the doublets at δ 6.17, 6.63 and 6.67, which originate from the benzo groups. The difference between the chemical shifts of the signal at high field (δ 6.17) and both the other doublets should be caused by different locations of the phenyl group. Only if the latter occupies the *cis* position at the heterocycle relative to the benzo group as in **12a**, 5-H is in the shielding region of the phenyl group and thus absorbs at rather high field. However, no information is available as to the configuration of C-1 of **12**.

The *cis* arrangement of the phenyl and benzo groups as in **12a** is assumed for **13** as well because of the doublet at δ 5.76 in the ^{1}H NMR spectrum, which is assigned to 5-H. In addition, the ^{1}H and ^{13}C NMR data of this compound correspond closely to those of the adduct of hydrogen chloride to **10**, whose configuration had been determined by an X-ray structure analysis to be analogous to that of **13**.[3a] The benzo group of the bromodihydro-α-pyrone displays ^{1}H NMR signals only in the region of δ 7.27–8.25. Molecular models indicate a rather rigid structure, in which the phenyl group is far away from 5-H only if the former occupies the *cis* position relative to the benzo group. Thus, structure **14** has been assigned to the bromodihydro-α-pyrone. The chemical shift of 3-H of the β-lactone, which is analogous to 5-H of **12**–**14**, answers the question of the configuration as well, which had not been specified previously.[3a] Since all the aromatic protons absorb in the region of δ 7.20–7.55, the location of the benzo group *trans* to the phenyl group at the cyclobutane moiety as shown in **11** is indicated. A NOESY spectrum at 600 MHz supported this assumption by revealing a strong interaction between the phenyl *ortho*-protons and both the cyclobutane protons.

β-Lactone **11** is formed on a pathway competing with that leading to γ-oxoketene **10**,[3a] and we had also prepared **11** previously by thermolysis of **10**, albeit in only 11% yield.[3a] We have repeated this experiment now and obtained an increased yield of 57%.

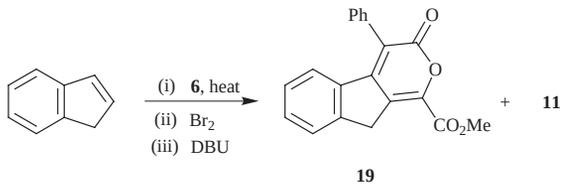
The products **12**, **13** and **14** have their origin in the reaction of **10** with bromine (Scheme 4). The formation of **12** should



Scheme 4

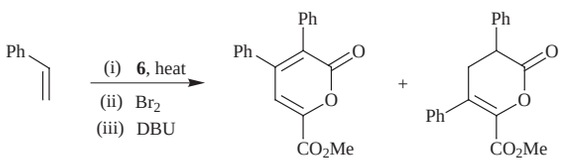
start with the transfer of a bromine cation to the ketene β-carbon atom to give an acylium ion **15**. Owing to the chirality of **10**, the ketene group has two diastereomorphic faces, which is why two diastereomers **15** can result. Cyclisation of **15** should generate the carbenium-oxonium ions **16**, the combination of which with the bromide ion could lead to four isomers of **12**, of which three have been observed. An alternative route to the conversion **15** ⟶ **16** could be the collapse of the ion pair at the stage of **15** generating the α-bromoacyl bromides **17**, which could be transformed to **16** *via* the zwitterions **18**. The bromodihydro-α-pyrone **14** is likely to be the result of spontaneous elimination of HBr from the diastereomer of **12a** with respect to the C-1 configuration, possibly *via* the corresponding ion pair **16**. Evidently, HBr is already generated, before complete consumption of the γ-oxoketene **10**, since the formation of the δ-bromo-δ-lactone **13** is best rationalised by the addition of HBr to **10**, in analogy to the reaction of HCl with **10**.[3a]

The plethora of products has been strongly reduced by treatment with DBU of the mixture from the addition of bromine to the solution of **10** without work-up. From this procedure, the α-pyrone **19** was isolated in 42% yield and had to be separated only from the β-lactone **11**. Under these conditions, the α,δ-dibromo-δ-lactones **12** as well as the bromodihydro-α-pyrone **14** undergo elimination of HBr with formation of **19**. In this experiment, neither **13** nor the dihydro-α-pyrone that would result from HBr elimination from **13** was observed (Scheme 5).



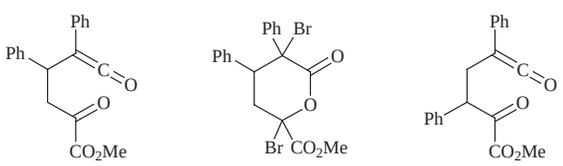
Scheme 5

After the reaction of styrene with **6** and addition of bromine to the resulting solution, no attempt was made to isolate a bromine adduct of a γ-oxoketene, but the reaction sequence was continued without work-up by treatment of the mixture with DBU, and the α-pyrone **20** as well as dihydro-α-pyrone **21** were isolated in yields of 44 and 4%, respectively (Scheme 6). The structure of **21** is based on the NMR data, in particular an ABX system in the ^{1}H NMR spectrum having δ values of 3.22, 3.33 and 5.21 and $J_{A,B} = 18$ Hz and thus indicating the allylic position of the methylene group.



Scheme 6

The formation of **20** is expected as a consequence of the initial formation of the γ-oxoketene **22**, described previously,[8] and its conversion into the bromine adducts **23** followed by bis(dehydrobromination). The γ-oxoketene **24**, which is the



regioisomer of **22** and for which no evidence was found in the former study,[8] has to be the precursor to **21**. This shows that the Diels–Alder reaction of oxadiazinone **6** and styrene proceeds in two orientations, as has been observed for the addition of styrene to diphenyloxadiazinone.[9] The pathway from **24** to **21** should be analogous to that proposed for the formation of the dihydro-α-pyrone **9** from γ-oxoketene **4**. Thus, **24** could be isomerised by HBr evolved on partial decomposition of **23**.

In conclusion, we have investigated the addition of bromine to three γ-oxoketenes and transformed the products to α-pyrones having three or four substituents. This reaction sequence complements the known methods for the preparation of α-pyrones[10] including our synthesis of 3,6-disubstituted α-pyrones from oxadiazinones.[1]

Experimental

General details

Melting points were determined with a Kofler hot stage from C. Reichert, Optische Werke A. G., Wien, Austria. IR Spectra were measured with a Perkin-Elmer 1420 ratio infrared spectrophotometer as KBr discs in the case of crystalline compounds or as solutions in CCl_4 in the case of reaction mixtures. The ^{1}H (200, 250 and 600 MHz) NMR and ^{13}C (50 and 63 MHz) NMR spectra were obtained on Bruker AC 200, AC 250 and WM 600 instruments in $CDCl_3$ (routine spectra) with the $CHCl_3$ signal as internal standard or C_6D_6 (NOESY spectrum of **12**) at room temperature. *J* Values are given in Hz. Elemental analyses were performed with a LECO CHNS 932 instrument. Mass spectra were obtained on a Finnigan MAT 90 instrument using the electron impact mode (70 eV). Tetrachloromethane, the solvent for the reactions of oxadiazinone **6** with the olefins, was purified by passing through basic Al_2O_3 of activity I. Flash chromatography was performed on SiO_2 (63–200 μm). The eluents light petroleum (referring to the fraction with bp 30–50 °C), dichloromethane and ethyl acetate were used as obtained commercially.

Methyl 5,6,7,8-tetrahydro-3-oxo-4-phenyl-5,8-methano-3*H*-2-benzopyran-1-carboxylate 7

A solution of methyl 6-oxo-5-phenyl-1,3,4-oxadiazine-2-carboxylate **6**[7a] (1.08 g, 4.65 mmol) and norbornene (481 mg, 5.11 mmol) in tetrachloromethane (13 cm^3) was refluxed until **6** had been consumed completely and an IR absorbtion at 2100 cm^{-1} (**4**) had attained its maximum intensity (2 h). After cooling to room temperature, a solution of bromine (816 mg, 5.11 mmol) in tetrachloromethane (7 cm^3) was added dropwise under stirring. At the beginning the reddish brown colour disappeared instantaneously, while at the end it persisted. Stirring was continued for 30 min and then a solution of DBU (1.41 g, 9.27 mmol) in tetrachloromethane (5 cm^3) was added, dropwise, at room temperature, during which time a voluminous brown solid precipitated. After 15 min of continued stirring, the mixture was filtered and the precipitate carefully washed with tetrachloromethane. The filtrate was concentrated *in vacuo* and the residue was purified by flash chromatography (SiO_2, light petroleum–ethyl acetate from 7:1 to 3:1) to afford, in order of elution, β-lactone **8**[7b] (159 mg, 11%), dihydro-α-pyrone **9**[3b] (54 mg, 4%) (both contaminated with unidentified components) and **7** (478 mg, 35%) as a yellowish solid; mp 190 °C; ν_{max}(KBr)/cm^{-1} 1715 (broad, C=O); δ_H(250 MHz, $CDCl_3$) 1.50–1.60 (2 H, m, *exo*-6-H and *exo*-7-H), 1.62 (1 H, dt, $J_{9,9}$ 9.8, $J_{5,9} = J_{8,9} = 1.2$, *anti*-9-H), 1.76 (1 H, dquint, $J_{5,9} = J_{endo\text{-}6,9} = J_{endo\text{-}7,9} = J_{8,9} = 1.5$, *syn*-9-H), 2.00–2.11 (2 H, m, *endo*-6-H and *endo*-7-H), 3.35, 4.03 (2 H, 2 × m, 5-H and 8-H), 3.94 (3 H, s, CH_3), 7.34–7.50 (5 H, m, Ph); δ_C(63 MHz, $CDCl_3$) 26.6, 26.8 (2 × CH_2, C-6 and C-7), 40.5, 42.1 (2 × CH, C-5 and C-8), 43.7 (CH_2, C-9), 52.4 (CH_3), 123.0 (C, C-8a), 128.2 129.4 (2 × CH, *m*-C and *o*-C), 128.5 (CH, *p*-C), 132.5, 133.9, 137.5 (3 × C, C-4, C-4a and *i*-C), 160.5, 160.6, 161.6 (3 × C, C-1, C-3 and *C*O$_2$CH$_3$) (Found: C, 72.54; H, 5.76. $C_{18}H_{16}O_4$ requires C, 72.96; H, 5.44%).

Reaction of bromine with the γ-oxoketene 10 generated from the oxadiazinone 6 and indene—formation of three diastereomeric methyl *cis*-4a,9a-1,4-dibromo-1,3,4,4a,9,9a-hexahydro-3-oxo-4-phenylindeno[2,1-*c*]pyran-1-carboxylates 12a,b,c, methyl (1α,4β,4aα,9aα)-1-bromo-1,3,4,4a,9,9a-hexahydro-3-oxo-4-phenylindeno[2,1-*c*]pyran-1-carboxylate 13 and methyl (4α,4aα)-4-bromo-3,4,4a,9-tetrahydro-3-oxo-4-phenylindeno[2,1-*c*]pyran-1-carboxylate 14

A solution of **6** (1.01 g, 4.35 mmol) and indene (1.51 g, 13.0 mmol) in tetrachloromethane (15 cm^3) was refluxed until **6** had been consumed completely and an IR absorbtion at 2100 cm^{-1} (**10**) had attained its maximum intensity (2.5 h). After cooling to room temperature, a solution of bromine (749 mg, 4.75 mmol) in tetrachloromethane (15 cm^3) was added dropwise under stirring. Right up until the end of the addition period the colour of the reagent disappeared instantaneously. An IR spectrum indicated that no **10** was left. Then the solvent and the excess of indene were evaporated *in vacuo* and the residue was purified by flash chromatography (SiO_2, light petroleum–dichloromethane from 2:1 to 1:2, the products were only eluted at eluent ratios of 1:1 and 1:2). The following fractions were obtained in order of elution: 256 mg (14%) of a 1.0:2.5:3.7 mixture of **12a**,**b**,**c** as a beige solid, a 1.0:2.5:3.0 mixture of **12b**,**c** (273 mg, 13%) and β-lactone **11**[3a] (157 mg,

11%) as yellow crystals, a 1.0:1.5 mixture of **11** (58 mg, 4%) and **13** (108 mg, 6%), 97 mg (6%) of **13** as yellow crystals, a 1.0:1.7 mixture of **13** (35 mg, 2%) and **14** (60 mg, 3%) and 176 mg (10%) of **14** as yellowish crystals. Pure **13** (colourless crystals, mp 188 °C) was obtained by recrystallisation from dichloromethane–ethyl acetate (1:1). Pure **14** (light beige crystals, mp 214 °C) crystallised after dissolution of the crude material in the minimum quantity of ethyl acetate and storage of the solution at −30 °C. The compounds **12** could not be purified further since they decomposed readily, as indicated by the formation of fumes, probably HBr, on opening of the flask after several days. An NMR spectrum taken of the contents of that flask no longer contained the signals of **12**.

12a δ_H(250 MHz, $CDCl_3$) 3.35 (2 H, d, line distance 8.9, 9-H_2), 4.02 (3 H, s, CH_3), 4.06 (1 H, ddd, 9a-H), 4.46 (1 H, d, $J_{4a,9a}$ 7.9, 4a-H), 6.17 (1 H, d, $J_{5,6}$ 7.9, 5-H); **12b** δ_H(250 MHz, $CDCl_3$) 3.12 (1 H, dd, $J_{9,9}$ 14.7, $J_{9,9a}$ 7.9), 3.47 (1 H, dd, $J_{9,9a}$ 11.8, 9-H_2), 3.69 (1 H, ddd, 9a-H), 4.03 (3 H, s, CH_3), 4.36 (1 H, d, $J_{4a,9a}$ 7.0, 4a-H), 6.63 (1 H, d, J 8.5, 5-H or 8-H), 7.64 (2 H, m, *o*-H); **12c** δ_H(250 MHz, $CDCl_3$) 2.71 (1 H, dd, $J_{9,9}$ 15.6, $J_{9,9a}$ 8.9), 2.93 (1 H, dd, $J_{9,9a}$ 7.3) (9-H_2), 3.73 (3 H, s, CH_3), 3.75 (1 H, ddd, 9a-H), 4.84 (1 H, d, $J_{4a,9a}$ 6.7, 4a-H), 6.67 (1 H, d, J 8.6, 5-H or 8-H). The signals of the aromatic protons in the ^{1}H NMR spectrum, not assigned above, are multiplets with relative intensities 1.0:3.3:1.9:1.3 at δ 6.90–7.01, 7.01–7.20, 7.27–7.35 and 7.38–7.52.

13 ν_{max}(KBr)/cm^{-1} 1765, 1740 (2 × C=O); δ_H(250 MHz, $CDCl_3$) 3.03 (1 H, dd, $J_{9,9}$ 16.5, $J_{9,9a}$ 9.8), 3.22 (1 H, dd, $J_{9,9a}$ 8.8) (9-H_2), 4.00 (3 H, s, CH_3), 4.02 (1 H, ≈q, 9a-H), 4.24 (1 H, dd, $J_{4,4a}$ 10.4, $J_{4a,9a}$ 8.8, 4a-H), 5.01 (1 H, d, 4-H), 5.76 (1 H, d, $J_{5,6}$ 7.6, 5-H), 6.77 (1 H, m), 6.94 (2 H, m, *o*-H), 7.09–7.17 (2 H, m), 7.20–7.34 (3 H, m, *m*-H, *p*-H); δ_C(63 MHz, $CDCl_3$) 34.8 (CH_2, C-9), 47.0, 47.3, 48.7 (3 × CH, C-4, C-4a and C-9a), 54.1 (CH_3), 88.6 (C, C-1), 124.2, 125.9 (2 × CH, 2 C of C-5, C-6, C-7 and C-8), 127.7, 127.8, 128.2 (3 × CH, *p*-C and 2 C of C-5, C-6, C-7, C-8), 127.9 (CH, *m*-C), 131.0 (CH, *o*-C), 132.9 (C, *i*-C), 139.5, 140.3 (2 × C, C-4b and C-8a), 165.7, 168.1 (2 × C, C-3 and CO_2CH_3) (Found: C, 59.71; H, 4.26. $C_{20}H_{17}BrO_4$ requires C, 59.86; H, 4.27%).

14 ν_{max}(KBr)/cm^{-1} 1775, 1715 (2 × C=O), 1690 (C=C); δ_H(250 MHz, $CDCl_3$) 3.83 (3 H, s, CH_3), 3.86 (1 H, dd, $J_{9,9}$ 24.0, $J_{4a,9}$ 2.6), 4.00 (1 H, dd, $J_{4a,9}$ 2.4) (9-H_2), 5.25 (1 H, t, 4a-H), 7.03 (2 H, m, *o*-H), 7.08 (2 H, m, *m*-H), 7.15 (1 H, ≈tt, *p*-H), 7.27 (1 H, m), 7.36–7.44 (2 H, m), 8.25 (1 H, m); δ_C(63 MHz, $CDCl_3$) 35.8 (CH_2, C-9), 52.4 (CH_3), 57.1 (CH, C-4a), 63.4 (C, C-4), 125.2, 126.1, 127.4, 129.1, 129.2 (5 × CH, C-5, C-6, C-7, C-8 and *p*-C), 127.1 (CH, *o*-C), 128.3 (CH, *m*-C), 134.5, 135.2, 136.36, 136.41 (4 × C, C-4b, C-8a, C-9a and *i*-C), 142.0 (C, C-1), 160.2, 164.9 (2 × C, C-3 and CO_2CH_3) (Found: C, 60.12; H, 3.86. $C_{20}H_{15}BrO_4$ requires C, 60.17; H, 3.79%).

β-Lactone 11

According to the above procedure, a solution of the γ-oxoketene **10** and some **11** was generated from 3.16 mmol of **6** and refluxed for 7 d. After this period, there was still a small IR-absorbtion of **10**, which did not change its intensity on continued heating. Work-up by chromatography as described previously [3a] afforded a 57% yield of **11**.

Methyl 3,9-dihydro-3-oxo-4-phenylindeno[2,1-*c*]pyran-1-carboxylate 19

Prepared from oxadiazinone **6** (323 mg, 1.39 mmol) and indene (484 mg, 4.17 mmol), the γ-oxoketene **10** was treated with bromine (244 mg, 1.53 mmol) at 0 °C as described above. After stirring had been continued for 20 min, a solution of DBU (423 mg, 2.78 mmol) in tetrachloromethane (5 cm^3) was added dropwise to the mixture. During this operation, the colour of the mixture changed to dark brown and a voluminous solid precipitated. Stirring was continued for 10 min after completion of the addition. Then, the mixture was filtered and the precipitate carefully washed with tetrachloromethane. The filtrate was concentrated *in vacuo* and the residue was purified by flash chromatography (SiO_2, at the beginning pure dichloromethane and subsequently with an addition of 1 and 2% ethyl acetate) to afford β-lactone **11** (eluted by pure dichloromethane, 89 mg, 20%) and **19** (eluted by dichloromethane–ethyl acetate 50:1, 186 mg, 42%) as light beige crystals, mp 264 °C; ν_{max}(KBr)/cm^{-1} 1730 (CH_3OC=O), 1690 (br), 1650; δ_H(200 MHz, $CDCl_3$) 4.00 (3 H, s, CH_3), 4.25 (2 H, s, CH_2), 6.83 (1 H, br d, J 8.0, 5-H or 8-H), 7.09 (1 H, tm, J 7.6, 6-H or 7-H), 7.37–7.47 (3 H, m), 7.47–7.58 (4 H, m); δ_C(50 MHz, $CDCl_3$) 34.9 (C-9), 52.7 (CH_3), 124.0 (C-9a), 125.5, 126.0, 127.4, 131.9 (C-5, C-6, C-7 and C-8), 128.7, 132.8, 135.9, 140.8, 146.8, 152.9 (C-1, C-4, C-4a, C-4b, C-8a and *i*-C), 129.1 (very high intensity, *p*-C and *m*- or *o*-C), 129.3 (*o*- or *m*-C), 160.6, 161.7 (C-3 and CO_2CH_3) (Found: C, 75.36; H, 4.51. $C_{20}H_{14}O_4$ requires C, 75.46; H, 4.43%).

Methyl 2-oxo-3,4-diphenyl-2*H*-pyran-6-carboxylate 20 and methyl 3,4-dihydro-2-oxo-3,5-diphenyl-2*H*-pyran-6-carboxylate 21

A solution of **6** (1.10 g, 4.74 mmol) and styrene (543 mg, 5.21 mmol) in tetrachloromethane (12 cm^3) was refluxed until **6** had been consumed completely and an IR absorbtion at 2100 cm^{-1} (**22, 24**) had attained its maximum intensity (1.5 h). This solution was treated as the corresponding solution in the preparation of **19** [(i) Br_2 (833 mg, 5.21 mmol), (ii) DBU (1.44 g, 9.47 mmol)]. Flash chromatography (SiO_2, light petroleum–ethyl acetate from 5:1 *via* 4:1 to 1:4) provided **20** (eluted by light petroleum–ethyl acetate 4:1, 644 mg, 44%) as yellowish crystals, mp 156 °C, and **21** (eluted by light petroleum–ethyl acetate 1:4, 59 mg, 4%) as a yellowish oil.

20 ν_{max}(KBr)/cm^{-1} 1740, 1725, 1640; δ_H(250 MHz, $CDCl_3$) 3.96 (3 H, s, CH_3), 7.09–7.30 (10 H, m, 2 C_6H_5), 7.33 (1 H, s, 5-H); δ_C(63 MHz, $CDCl_3$) 53.0 (CH_3), 114.0 (CH, C-5), 128.0, 128.4, 128.6, 130.4 (4 × CH, *m*-C and *o*-C), 128.3, 129.1 (2 × CH, *p*-C), 129.2, 132.9, 136.3 (3 × C, C-3 and *i*-C), 146.6, 150.4 (2 × C, C-4 and C-6), 159.9, 160.8 (2 × C, C-2 and CO_2CH_3) (Found: C, 74.48; H, 4.77. $C_{19}H_{14}O_4$ requires C, 74.50; H, 4.60).

21 δ_H(250 MHz, $CDCl_3$) 3.23 (1 H, dd, $J_{4,4}$ 18.0, $J_{3,4}$ 5.2), 3.32 (1 H, dd, $J_{3,4}$ 5.5) (4-H_2), 3.85 (3 H, s, CH_3), 5.21 (1 H, t, 3-H), 7.02 (2 H, m), 7.08 (2 H, m) (2 × *o*-H), 7.15–7.23 (6 H, m, 2 × *m*-H, 2 × *p*-H); δ_C(63 MHz, $CDCl_3$) 32.8 (CH_2, C-4), 53.0 (CH_3), 73.5 (CH, C-3), 127.6, 128.7 (2 × CH, 2 × *p*-C), 127.9, 128.2 (particularly high intensity), 130.6 (3 × CH, 2 × *m*-C and 2 × *o*-C), 129.2, 134.1, 137.6 (3 × C, C-5 and 2 × *i*-C), 149.2 (C, C-6), 163.4, 169.8 (2 × C, C-2 and CO_2CH_3); *m*/*z* (EI) 308 (M^+, 23%), 250 (17), 249 ($M^+ - CO_2CH_3$, 100), 231 (23), 205 (17), 191 (16), 115 (16), 105 (18) [Found (EI): M^+, 308.1047. $C_{19}H_{16}O_4$ requires *M*, 308.1049].

Acknowledgements

We thank the Fond der Chemischen Industrie and NATO for financial support.

References

1 Part 15, M. Christl, G. Bodenschatz, E. Feineis, J. Hegmann, G. Hüttner, S. Mertelmeyer and K. Schätzlein, *Liebigs Ann.*, 1996, 853.
2 See ref. 1 and the other papers of this series.
3 (*a*) J. Hegmann, E. Ditterich, G. Hüttner, M. Christl, E.-M. Peters, K. Peters and H. G. von Schnering, *Chem. Ber.*, 1992, **125**, 1913; (*b*) M. Christl, G. Bodenschatz, E. Feineis, J. Hegmann, G. Hüttner, S. Mertelmeyer, K. Schätzlein and H. Schwarz, *J. Prakt. Chem.*, 1995 **337**, 659.
4 R. S. Brown, M. Christl, J. Ma, A. J. Lough, E.-M. Peters, K. Peters, F. Sammtleben, K. Sung, H. Slebocka-Tilk and T. T. Tidwell, *J. Org. Chem.*, in press.

5 V. W. Gash, D. E. Bissing (Monsanto Co.), Ger. Offen. 2,247,764/1973 (*Chem. Abstr*., 1973, **78**, 158969t); W. T. Brady and R. A. Owens, *Tetrahedron Lett.*, 1976, 1553; Y. Ogata and K. Adachi, *J. Org. Chem.*, 1982, **47**, 1182.
6 R. S. Brown, *Acc. Chem. Res.*, 1997, **30**, 131; G. Bellucci and C. Chiappe, *J. Chem. Soc.*, *Perkin Trans. 2*, 1997, 581 and ref. cited therein.
7 (*a*) M. Christl, U. Lanzendörfer, M. M. Grötsch, E. Ditterich and J. Hegmann, *Chem. Ber.*, 1990, **123**, 2031; (*b*) J. Hegmann, M. Christl, K. Peters, E.-M. Peters and H. G. von Schnering, *Tetrahedron Lett.*, 1987, **28**, 6429.
8 M. Christl, U. Lanzendörfer, M. M. Grötsch, J. Hegmann, E. Ditterich, G. Hüttner, E.-M. Peters, K. Peters and H. G. von Schnering, *Chem. Ber.*, 1993, **126**, 797.
9 M. Christl, U. Lanzendörfer, J. Hegmann, K. Peters, E.-M. Peters and H. G. von Schnering, *Chem. Ber.*, 1985, **118**, 2940.
10 J. D. Hepworth, in *Comprehensive Heterocyclic Chemistry*, ed. A. R. Katritzky and C. W. Rees, Pergamon Press, Oxford, 1984, vol. 3, p. 789; J. D. Hepworth, C. D. Gabbutt and B. M. Heron, in *Comprehensive Heterocyclic Chemistry II*, ed. A. R. Katritzky, C. W. Rees and E. F. V. Scriven, Pergamon-Elsevier, Oxford, 1996, vol. 5, p. 411.

Paper 8/02364F
Received 26*th March* 1998
Accepted 8*th May* 1998