4. A New General Synthesis of 2,2-Dialkyl-2,3-dihydro-4*H*-pyran-4-ones and Their Application for the *in situ* Preparation of Electron-Rich Dienes in Carbonyl-Alkyne Exchange Reactions with Acetylenes[1])

by **Daniel Obrecht**

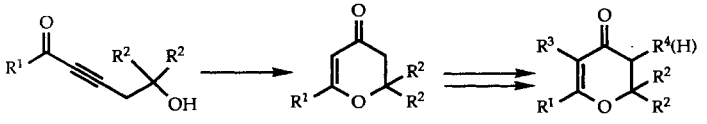
Zentrale Forschungseinheiten, *F. Hoffmann-La Roche AG*, CH-4002 Basel

(19.X. 90)

The substituted 2,2-dialkyl-2,3-dihydro-4*H*-pyran-4-ones of type **II** and **III** have been prepared by acid-catalyzed cyclization of the corresponding substituted acetylenic ketones **I** in good to excellent yields (*Scheme 1*). These 2,2-dialkyl-2,3-dihydro-4*H*-pyran-4-ones **II** and **III** have been used for the *in situ* preparation of highly reactive dienes of type **IV**–**VI** (*Scheme 2*) in carbonyl-alkyne exchange reactions with electron-poor alkynes **VII** to yield the highly substituted aromatic compounds **VIII** and **IX**. These reactions proceed in good yields and with excellent degree of regioselectivity. Aryl-substituted 2,2-dialkyl-2,3-dihydro-4*H*-pyran-4-ones **III** (R^1 = Ar) subsequently yield highly substituted biaryls. Reaction mechanisms are presented for the formation of the 2,2-dialkyl-2,3-dihydro-4*H*-pyran-4-ones as well as for the carbonyl-alkyne exchange reactions with electron-poor acetylenes.

1. Introduction. – Substituted 2,2-dialkyl-2,3-dihydro-4*H*-pyran-4-ones of type **III** (*Scheme 1*) are well known compounds which have been described with a number of different substituents R^1, R^2, R^3, and R^4. Such compounds are readily accessible by two different strategies. *Gelin* and coworkers have described the condensation of 2-acylacetic acids with 3,3-dialkyl-acryloyl chloride [1] and *Vereshchagin* and coworkers have pioneered the acid-catalyzed cyclization of substituted acetylenic ketones [2]. Recently, we have improved the cyclization method [2] by the use of aq. HBr as acid catalyst [3].

Scheme 1



I **II** **III**

Although the syntheses of 2,2-dialkyl-2,3-dihydro-4*H*-pyran-4-ones **II** and **III** (*Scheme 1*) have been studied quite extensively, relatively little is known about their chemistry and use as synthetic building blocks. *Gelin, e.g.*, has studied the base-catalyzed ring openings [1], whereas *Dreux* has described the addition of *Grignard* reagents [4].

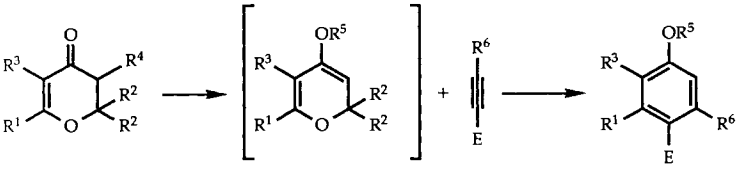
We describe in this paper a further improvement of the cyclization of substituted acetylenic ketones of type **I** [2] [3] to **II** using 33% HBr/AcOH in CH_2Cl_2 at room

[1]) Presented in part at the autumn meeting of the Swiss Chemical Society in Bern on October 20, 1989.

temperature (*Scheme 1*). Using this protocol, the 2,2-dialkyl-2,3-dihydro-4*H*-pyran-4-ones **II** are obtained under very mild conditions in good-to-excellent yields (*Table 2*). In addition, we present a convenient bromination of **II** at C(5) (*Scheme 4*, *Table 2*).

Furthermore, we describe the use of 2,2-dialkyl-2,3-dihydro-4*H*-pyran-4-ones as precursors for the *in situ* preparation of electron-rich dienes of type **IV–VI** and the carbonyl-alkyne exchange reaction (CAE reaction) with electron-poor acetylenes **VII** to yield the highly substituted aromatic compounds of type **VIII** and **IX** (*Scheme 2*). This

Scheme 2

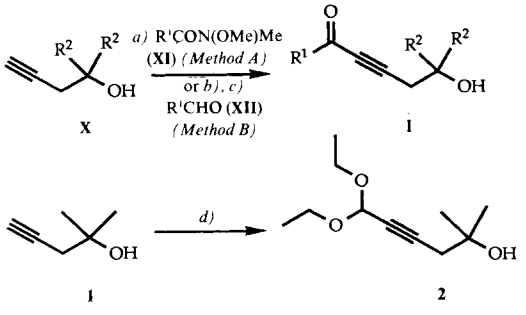


II or III (R^4 = H) IV $R^5 = R^7R^8{}_2Si$; V R^5 = Me; VI R^5 = MeCO VII VIII $R^5 = R^7R^8{}_2Si$; IX R^5 = H

CAE reaction, well known for 2*H*-pyran-2-ones [5–7] and 2*H*-pyrans [5], proceeds with the *in situ* prepared silyl enol ethers **IV** ($R^5 = R^7R^8{}_2Si$), methyl enol ethers **V** (R^5 = Me), and enol acetates **VI** (R^5 = MeCO; *Scheme 2*) with high degree of regioselectivity and under very mild conditions. In cases where R^1 = Ar, this novel transformation yields highly substituted biaryls, compounds which have recently attracted very much attention [8]. In addition, results of mechanistic investigations of the acid-catalyzed cyclizations and the CAE reactions are presented and discussed.

2. Substituted Acetylenic Ketones of Type I. – Ketones of type **I** (*Scheme 1*) were readily prepared from the known 1,1-dialkylbut-3-ynols **X** (**1** (R^2 = Me) and **4** (R^2 = i-Pr)). These compounds were conveniently prepared from propargyl bromide and the corresponding ketones [9], following our earlier described route [3] (*Scheme 3*). The

Scheme 3



a) (i-Pr)MgCl, THF, R^1CON(OMe)Me (**XI**). *b*) (i-Pr)MgCl, THF, R^1CHO (**XII**). *c*) MnO_2, CH_2Cl_2, 0° → r.t. *d*) (i-Pr)MgCl, THF, $(EtO)_2CHOPh$ (**12**), 50° (72%).

Table 1. *Synthesis of the Substituted Acetylenic Ketones of Type* **I**. See *Scheme 3*.

Acetylenic alcohol **X**	$R^1CON(OMe)Me$ **XI**	R^1CHO **XII**	*Method*	Acetylenic ketone **I**	R^1	R^2	Yield [%]
1	**5**		*A*	**13**	Me	Me	61.1
1	**6**		*A*	**14**	Ph	Me	90.4
1		**7**	*B*	**14**	Ph	Me	85.0
4	**6**		*A*	**15**	Ph	i-Pr	88.4
1	**8**		*A*	**16**	*t*-Bu	Me	75.0
1		**9**	*B*	**17**	COOMe	Me	61.0
1	**10**[a])		*A*	**18**	CH_2COOEt	Me	43.7
1		**11**	*B*	**19**	$2\text{-}(MeO)C_6H_4$	Me	67.0
1		**12**[b])	*B*	**2**[c])	H	Me	71.9

[a]) Instead of amide **XI**, the corresponding commercially available acyl chloride **10** was used.
[b]) Corresponding diethyl acetal **12** was used.
[c]) Corresponding diethyl acetal (R^1 = H).

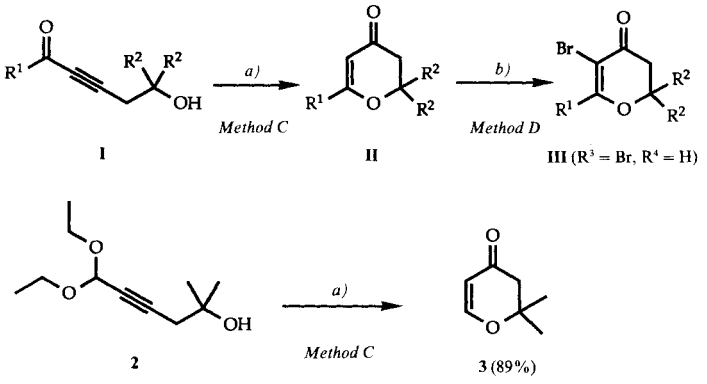
acetylenic alcohols **X** were treated with 2.2 equiv. of (i-Pr)MgCl in THF at room temperature for 4 h, followed either by addition of the *N*-methoxy-*N*-methylamides of type **XI** (**5**, **6**, and **8**) and mild hydrolysis (*Method A*) to yield the acetylenic ketones **I** (**13**–**16**, *Table 1*) or by addition of the corresponding aldehydes **XII** (**7**, **9**, and **11**) and oxidation with MnO_2 in CH_2Cl_2 (*Method B*) to yield **I** (**14**, **17**, and **19**, *Table 1*). The yields were 60–90% using *Method A* and 61–85% using *Method B*, based on isolated and purified products (*Table 1*). The corresponding starting material for R^1 = H was conveniently prepared as the diethyl acetal **2** using a modified procedure of *Barbot* [10] (*Scheme 3*), and acetylenic ketone **18** ($R^1 = CH_2COOEt$) was prepared following *Method A* but using the commercially available (ethoxycarbonyl)acetyl chloride (**10**; *Table 1*).

3. 2,2-Dialkyl-2,3-dihydro-4*H*-pyran-4-ones of Type II and III. – 3.1. *Acid-catalyzed Cyclization of Acetylenic Ketones* **I** *to* **II** *and Bromination at C(5)*. As mentioned in *Chapt. 1*, we found a general and efficient modification of the earlier described conditions [2] [3] for the acid-catalyzed cyclizations of the acetylenic ketones **I** to the 2,2-dialkyl-2,3-dihydro-4*H*-pyran-4-ones of type **II**. Replacement of aq. HBr/toluene (80°) [3] by HBr/AcOH in CH_2Cl_2 at 0° to room temperature yielded **II** (**3**, **20**, **22**, **24**, **26**–**29**) in good to excellent yields (67–96%; *cf. Table 2*). During our search to find efficient methods for

Table 2. *Synthesis of the 2,2-Dialkyl-2,3-dihydro-4*H*-pyran-4-ones of Type* **II** *and* **III**. See *Scheme 1*.

Acetylenic ketone **I**	*Method*	Pyranone **II**	Pyranone **III**	R^1	R^2	R^3	Yield [%]
2	*C*	**3** [18]		H	Me	H	89.0
13	*C*	**20** [1]		Me	Me	H	86.8
	D		**21**	Me	Me	Br	86.4
14	*C*	**22** [2] [3]		Ph	Me	H	87.3
	D		**23**	Ph	Me	Br	92.6
15	*C*	**24**		Ph	i-Pr	H	91.8
	D		**25**	Ph	i-Pr	Br	94.8
16	*C*	**26** [10]		*t*-Bu	Me	H	91.0
17	*C*	**27**		COOMe	Me	H	66.9
18	*C*	**28**		CH_2COOEt	Me	H	72.6
19	*C*	**29**		$2\text{-}(MeO)C_6H_4$	Me	H	96.3

Scheme 4

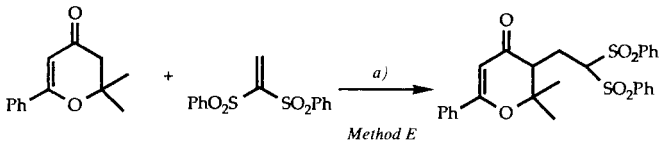


a) 33% HBr/AcOH, CH_2Cl_2, 0° → r.t. *b*) NBS, $CHCl_3$, 0° → r.t.

introducing further substituents R^3 and R^4, we discovered that compounds of type **II** could be easily brominated with *N*-bromosuccinimide (NBS) in $CHCl_3$ (*Scheme 4*). The isolated yields for this transformation of **II** (**20**, **22**, **24**) into **III** (**21**, **23**, **25**) were excellent (86–95%; *cf. Table 2*).

Substituents R^4 at C(3) of the 2,2-dialkyl-2,3-dihydro-4*H*-pyran-4-ones **II** are most conveniently introduced by reaction of the corresponding silyl enol ether (prepared by reaction of **II** with 1.2 equiv. of (*tert*-butyl)dimethylsilyl trifluoromethanesulfonate ((*t*-Bu)Me_2SiOTf) and 1.3 equiv. of 2,6-di(*tert*-butyl)pyridine ((*t*-Bu)$_2C_5H_3N$) in $CHCl_3$ [11]) with an appropriate electrophile. Using this method, reaction of **22** with 1,1-bis(phenylsulfonyl)ethene (**65**) afforded the C(3)-substituted derivative **66** in 96% yield (*Scheme 5*).

Scheme 5

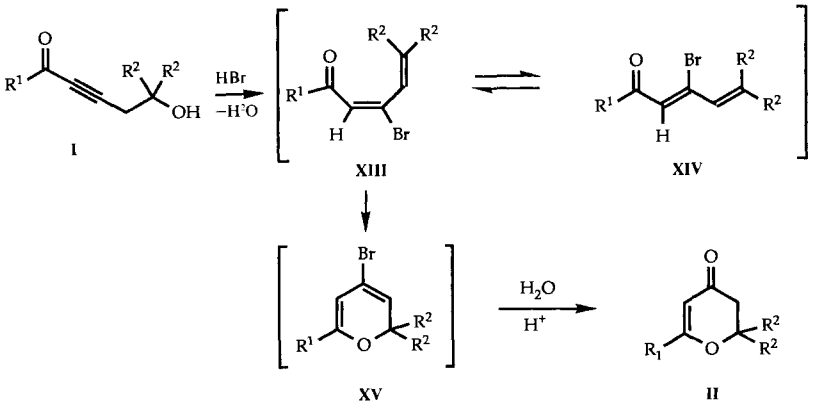


a) (*t*-Bu)$_2C_5H_3N$, (*t*-Bu)Me_2SiOTf, $CHCl_3$, 0° → r.t. (96%).

With this set of reactions, a wide range of new highly substituted 2,2-dialkyl-2,3-dihydro-4*H*-pyran-4-ones of type **III** (*Schemes 2* and *4*) has become readily accessible (*cf. Table 2*).

3.2. *Mechanistic Studies.* Under the cyclization conditions used by *Vereshchagin* [2] (aq. H_2SO_4/EtOH, 100°), the reaction mechanism probably involves hydrolysis of the acetylenic ketones **I** to the corresponding β-diketones, cyclization, and dehydration to **II**. For the acid-catalyzed cyclizations with HBr, however, we propose that ketones **I** are first transformed, by addition of HBr and elimination of H_2O, to a mixture of (*Z*)- and (*E*)-bromo-dienones **XIII** and **XIV**, which rapidly interconvert under the reaction condi-

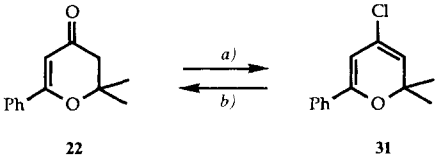
Scheme 6



tions (*Scheme 6*). The (*E*)-isomers **XIII**, thus, react in a 6π-electrocyclization to the bromo-2*H*-pyran derivatives **XV**, which are transformed under the reaction conditions into the corresponding 2,2-dialkyl-2,3-dihydro-4*H*-pyran-4-ones **II**.

The following observations provide strong support for this mechanism. First, the isolable chloro-2*H*-pyran **31** (*Scheme 7*), prepared by treatment of **22** with 1.5 equiv. of oxalyl chloride and a catalytic amount of DMF in CH_2Cl_2 in 96% yield, provides **22** under the standard cyclization conditions. Second, the 4-chloro-2*H*-pyran **31** shows similar TLC properties with the most apolar spot from the cyclization reaction mixture (*e.g.* **14** → **22**) which slowly disappears during the course of the reaction.

Scheme 7



a) $(COCl)_2$, cat. DMF, CH_2Cl_2 (96%). *b*) HBr/AcOH, CH_2Cl_2, r.t. (*Method C*).

4. Carbonyl-Alkyne Exchange (CAE) Reactions of *in situ*-Prepared Electron-Rich Dienes IV–VI Derived from II and III with Electron-Poor Acetylenes VII. – 4.1. *General.* While the CAE reactions have been extensively studied for 2*H*-pyran-2-ones of type **XXII** (see below, *Scheme 14*) [6] [7], there are only a few examples in the case of 2*H*-pyrans of type **XXIII** [5]. *Danishefsky* and coworkers have shown, that the acyclic electron-rich dienes of type **XXV** [12] undergo *Diels-Alder* reactions with electron-poor acetylenes **VII** (*Scheme 2*) to yield, after elimination of ROH, highly substituted aromatic compounds of type **VIII**. Although the regioselectivities of these acyclic dienes in the CAE reactions are usually excellent (in contrast to those of **XXII** and **XXIII**), there is only a little variation of R^1 and R^3 described in the literature so far. To our knowledge,

Table 3. *CAE Reactions of* **II** *or* **III** *with Acetylenes* **VII**. See *Scheme 8*.

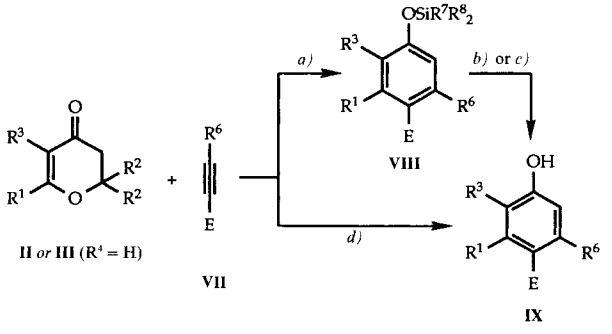
4*H*-Pyran-4-one **II** or **III**	Acetylene **VII**	*Method*	Silylated phenol **VIII**	Phenol **IX**	R^1	R^2	R^3	R^6	E	R^7	R^8	Yield [%]
22	**32**	*E*	**33**		Ph	Me	H	H	PhCO	*t*-Bu	Me	96.8
22	**32**	*E*	**34**		Ph	Me	H	H	PhCO	i-Pr	i-Pr	90.4
		HCl/MeOH		**35**	Ph	Me	H	H	PhCO			93.0
22	**32**	*F*		**35**	Ph	Me	H	H	PhCO			83.7
22	**36**	*E*	**37**		Ph	Me	H	Me	PhCO	i-Pr	i-Pr	95.0
		HCl/EtOH		**38**	Ph	Me	H	Me	PhCO			93.4
22	**39**	*E*	**40**		Ph	Me	H	COOMe	COOMe	i-Pr	i-Pr	68.7
		HCl/MeOH		**41**	Ph	Me	H	COOMe	COOMe			93.6
22	**42**	*E*	**43**		Ph	Me	H	H	COOEt	i-Pr	i-Pr	56.8
		HCl/EtOH		**44** [13]	Ph	Me	H	H	COOEt			99.0
22	**45**	*E*	**46**		Ph	Me	H	COOMe	PhCO	*t*-Bu	Me	98.0
		HCl/MeOH		**47**	Ph	Me	H	COOMe	PhCO			90.5
22	**48**	*E*	**49**		Ph	Me	H	$(EtO)_2CH$[a])	PhCO	*t*-Bu	Me	98.0
		HCl/EtOH		**50**	Ph	Me	H	CHO	PhCO			91.0
23	**32**	*F*		**51**	Ph	Me	Br	H	PhCO			59.0
26	**36**	*E*	**52**		*t*-Bu	Me	H	Me	PhCO	*t*-Bu	Me	74.0
		HCl/EtOH		**53**	*t*-Bu	Me	H	Me	PhCO			94.0
26	**39**	*E*	**54**		*t*-Bu	Me	H	COOMe	COOMe	i-Pr	i-Pr	60.2
		HCl/MeOH		**55**	*t*-Bu	Me	H	COOMe	COOMe			91.4
29	**32**	*E*	**56**		2-$(MeO)C_6H_4$	Me	H	H	PhCO	thexyl	Me	87.5
		HCl/EtOH		**57**	2-$(MeO)C_6H_4$	Me	H	H	PhCO			93.0
29	**39**	*E*	**58**		2-$(MeO)C_6H_4$	Me	H	COOMe	COOMe	i-Pr	i-Pr	79.2
		Bu_4NF		**59**	2-$(MeO)C_6H_4$	Me	H	COOMe	COOMe			90.0
30	**36**	*F*		**60**	Ph	Me	COOEt	Me	PhCO			47.0
30	**39**	*E*	**61**		Ph	Me	COOEt	COOMe	COOMe	thexyl	Me	58.0
		Bu_4NF		**62**	Ph	Me	COOEt	COOMe	COOMe			90.7

[a]) During the aq. workup and FC, the acetal group was hydrolyzed to R^6 = CHO.

2,2-dialkyl-2,3-dihydro-4*H*-pyran-4-ones **II** (or **III**) have never been described in connection with CAE reactions, such as shown in *Scheme 2*.

4.2. Via *Silyl Enol Ethers of* **II** *or* **III**. The best conditions for the *in situ* preparation of the silyl enol ethers of type **IV** from **II** or **III** (see *Scheme 2*) were either the use of 2.5 equiv. of $(t\text{-Bu})_2C_5H_3N$ and 2.2 equiv. of a bulky trialkylsilyl trifluoromethanesulfonate $R^7R^8{}_2SiOTf$ ($R^7 = R^8 =$ i-Pr; $R^7 = t$-Bu, $R^8 =$ Me; $R^7 =$ thexyl, $R^8 =$ Me) in $CHCl_3$ at room temperature to 60° (*Method E*; *cf. Table 3*) or the use of 2.5 equiv. of Me_3SiOTf and 2.2 equiv. of $(t\text{-Bu})_2C_5H_3N$ in $CHCl_3$ (*Method F*; *cf. Table 3*) at room temperature. When $R^7R^8{}_2SiOTf$ was used, the highly substituted silylated phenols of type **VIII** were obtained from **II** or **III** and **VII** in excellent yields (*Scheme 8*), after purification by flash chromatography (FC) [15]. These compounds **VIII** could then be hydrolyzed to the crystalline phenols **IX**. When Me_3SiOTf (*Method F*) was used, phenols **IX** were directly obtained after quenching the reaction mixture with HCl/MeOH (*Scheme 8*).

Scheme 8



a) $(t\text{-Bu})_2C_5H_3N$ (2.5 equiv.), $R^7R^8{}_2SiOTf$ (2.2 equiv.), $CHCl_3$ 0°→60° (*Method E*). *b*) ROH (R = Me or Et), 2N aq. HCl soln., 60–80°. *c*) Bu_4NF, THF, r.t. *d*) $(t\text{-Bu})_2C_5H_3N$ (2.2 equiv.), Me_3SiOTf (2.5 equiv.), $CHCl_3$, 0°→r.t., then MeOH, 2N aq. HCl (*Method F*).

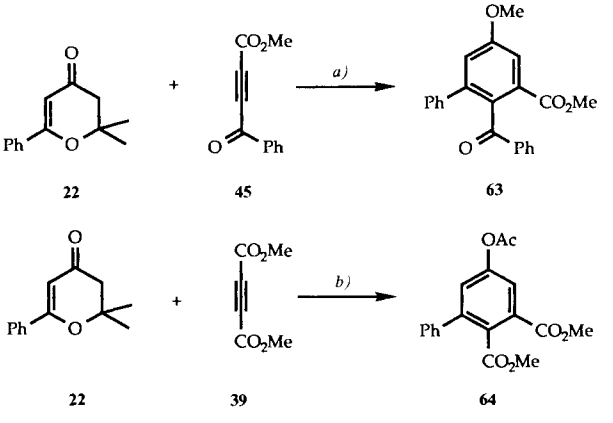
As depicted in *Table 3*, the 2,3-dihydro-2,2-dimethyl-4*H*-pyran-4-ones **II** or **III** ($R^2 =$ Me; **22**, **23**, **26**, **29**, and **30**) were chosen as models for the CAE reactions with electron-poor acetylenes **VII** (**32**, **36**, **39**, **42**, **45**, and **48**). When **VII** was unsymmetrical (**32**, **36**, **42**, **45**, **48**), the reactions were completely regioselective. The observed regiochemistry is in accordance with simple FMO considerations and with earlier published work [5]. It is interesting to note, that the CAE reactions work especially well for **22** ($R^1 =$ Ph), **29** ($R^1 =$ 2-(MeO)C_6H_4), and even for **26** ($R^1 = t$-Bu), which demonstrates the high reactivity of the *in situ*-prepared electron-rich dienes of type **IV** (*Scheme 2*). Furthermore, even the very acid-labile acetal group of acetylene **48** ($R^6 = (OEt)_2CH$) is compatible with the mild reaction conditions (*Method E*), yielding, after hydrolytic workup, the highly functionalized biphenylcarbaldehyde **50** ($R^6 =$ CHO) in 90% overall yield.

Substituents (Br, COOEt) at C(5) of the 2,3-dihydro-2,2-dimethyl-4*H*-pyran-4-ones **III** ($R^2 =$ Me; **23** and **30**) generally decrease the reactivity towards the CAE reactions. The additional substituent R^3 presumably slows down the formation of the intermediate silyl enol ether **IV** due to steric reasons. These dienes, however, once formed, are thermo-

dynamically more stable and thus less susceptible towards the undesired electrocyclic ring opening (see below (*Scheme 10*) and *Chapt. 4.5*). For these reasons, the use of the much more reactive silylating agent Me_3SiOTf (*Method F*) is preferred when $R^3 \neq H$. The excess of Me_3SiOTf presumably serves as a *Lewis*-acid catalyst.

4.3. Via *Enol Ethers and Enol Acetates of* **II**. In analogy to the *in situ*-prepared sily enol ethers **IV** from **II** or **III**, compounds **II** or **III** can also be transformed into the corresponding methyl enol ethers **V** ($R^5 = Me$) and enol acetates **VI** ($R^5 = MeCO$; *Scheme 2*). Such enol ethers and enol acetates also undergo the CAE reactions with electron-poor acetylenes of type **VII** as exemplified in *Scheme 9*. The enol ether of 4*H*-pyran-4-one **22**, generated *in situ* by reaction with 2.2 equiv. Me_3OBF_4 and 2.5 equiv. of $(t\text{-Bu})_2C_5H_3N$ in $CHCl_3$, yields with acetylene **45** the highly substituted aromatic compound **63** in 57% isolated yield (87% based on recovered starting material), whereas the enol acetate, generated *in situ* by reaction of **22** with excess of isopropenyl acetate and a catalytic amount of TsOH in toluene, yields with acetylene **39** the corresponding aromatic compound **64** in 90.5% isolated yield (*Scheme 9*). The latter process is especially promising, considering the ease of handling, the low cost of the reagents, and the high yield of isolated product.

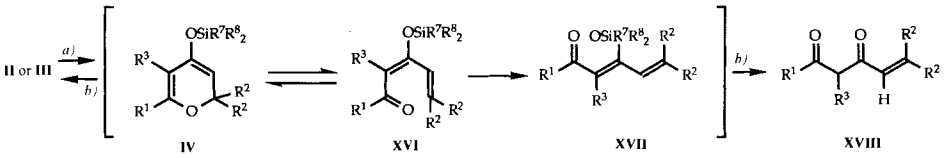
Scheme 9



a) $(t\text{-Bu})_2C_5H_3N$, Me_3OBF_4, $CHCl_3$, r.t. (87%). *b*) Isopropenyl acetate, TsOH, $CHCl_3$, 75° (90.5%).

4.4. *Mechanistic Considerations.* 4.4.1. *Stability of the* in situ-*Prepared Silyl Enol Ethers, Enol Ethers, and Enol Acetates Derived from* **II** *or* **III**. As mentioned earlier, the 2,2-dialkyl-2,3-dihydro-4*H*-pyran-4-ones **II** or **III** can be transformed into the corresponding β-diketones of type **XVIII** by a base-catalyzed, probably electrocyclic ring opening [1]. Under acidic conditions, these β-diketones **XVIII** yield **II** or **III** [1]. A similar electrocyclic equilibrium of ring-opened and -closed forms is known for the parent 2*H*-pyrans [5]. Based on these facts, we reasoned that such an equilibrium might also exist in the case of the *in situ*-prepared silyl enol ethers **IV** ($R^5 = SiR^7R^8_2$), enol ethers **V** ($R^5 = Me$), and enol acetates **VI** ($R^5 = MeCO$, *Scheme 2*). Careful analysis of the hydrolysis products **II** or **III** and **XVII**, generated from the mixture of silyl enol ethers **IV**, **XVI**, and **XVII** (*Scheme 10*), revealed the expected lability of the intermediates **IV**

Scheme 10



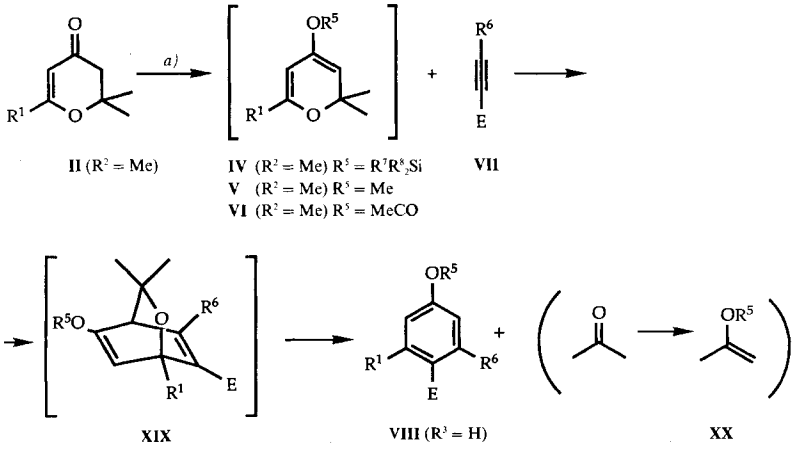
a) Base (2.2–2.5 equiv.), $R^7R^8_2SiOTf$ (2.2–2.5 equiv.), $CHCl_3$. *b*) 2N aq. HCl soln.

towards certain bases (*e.g.* Et_3N, NaOH) and their stability towards acids (TsOH, Me_3SiOTf). It was finally found, that the use of $(t\text{-Bu})_2C_5H_3N$ instead of Et_3N [11] for the *in situ* preparation of the silyl enol ethers of type **IV** completely suppressed the formation of **XVI** and **XVII** and thus of **XVIII** after hydrolysis. These observations led to the development of the conditions described in *Methods E* and *F* (see *Chapt. 4.4.2*). As noted previously, the silyl enol ethers **IV** bearing substituents at C(5) were generally more stable and less susceptible towards electrocyclic ring opening, but their preparation required higher temperatures (60° instead of room temperature, *Method E*) or the more reactive Me_3SiOTf as silylating reagent (*Method F*).

4.4.2. *Mechanistic Studies of the CAE Reactions.* In the cases of the 2*H*-pyran-2-ones of type **XXII** [6] [7] and the 2*H*-pyrans of type **XXIII** [5] (see below, *Scheme 14*), it is generally accepted, that the CAE reactions proceed *via* two sequential concerted processes, namely a [4 + 2] cycloaddition followed by a [4 + 2] cycloreversion with extrusion of CO_2 or acetone. In the case of open-chain silyl enol ethers, *Mukaiyama* has produced experimental evidence for two sequential *Lewis* acid catalyzed *Michael* additions [14], whereas in the case of the '*Danishefsky* dienes', the concerted mechanism was favored [12].

We believe that the silyl enol ethers of type **IV** ($R^5 = R^7R^8_2Si$), generated from **II** by *Method E*, the enol ether **V** (R^1 = Ph, $R^2 = R^5$ = Me), and the enol acetate **VI** (R^1 = Ph,

Scheme 11

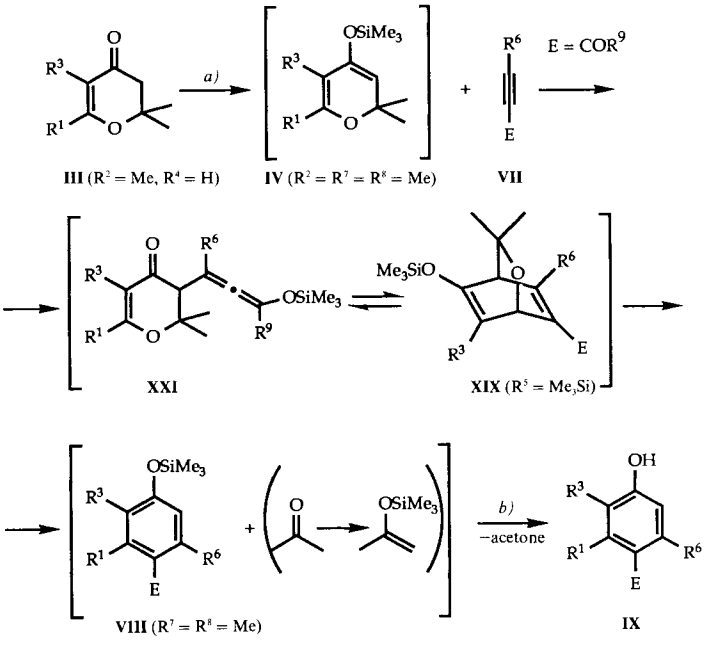


a) $(t\text{-Bu})_2C_5H_3N$ (2.5 equiv.), $R^7R^8_2SiOTf$ (2.2 equiv.), $CHCl_3$ ($R^5 = R^7R^8_2Si$), or $(t\text{-Bu})_2C_5H_3N$ (2.5 equiv.), Me_3OBF_4, $CHCl_3$ (R^5 = Me), or isopropenyl acetate, TsOH, toluene (R^5 = Ac).

R^2 = Me, R^5 = MeCO) derived from **22**, follow the mechanism presented in *Scheme 11*. These *in situ*-prepared dienes of type **IV–VI** would react in *Diels-Alder* fashion with electron-poor acetylenes **VII** to the non-isolable intermediates **XIX**, which upon extrusion of acetone (R^2 = Me) yield the highly substituted aromatic compounds **VIII** and the ketone derivative **XX**[2]).

In the cases where Me_3SiOTf was used as the silylating agent (*Method F*), we can not exclude a '*Mukaiyama*'-type reaction pathway as depicted in *Scheme 12*. In these cases, the *in situ*-formed silyl enol ethers **IV** (from **III**) would react with acetylene **VII** in two sequential *Lewis* acid catalyzed *Michael* additions *via* **XXI** to the bicyclic intermediates **XIX** (*Scheme 12*), which upon extrusion of acetone yield **VIII** and the highly substituted phenols **IX** after hydrolysis.

Scheme 12



a) (t-Bu)$_2C_5H_3N$ (2.2 equiv.), Me_3SiOTf (2.5 equiv.), $CHCl_3$, 0°→r.t. (*Method F*). *b*) 2N aq. HCl, MeOH.

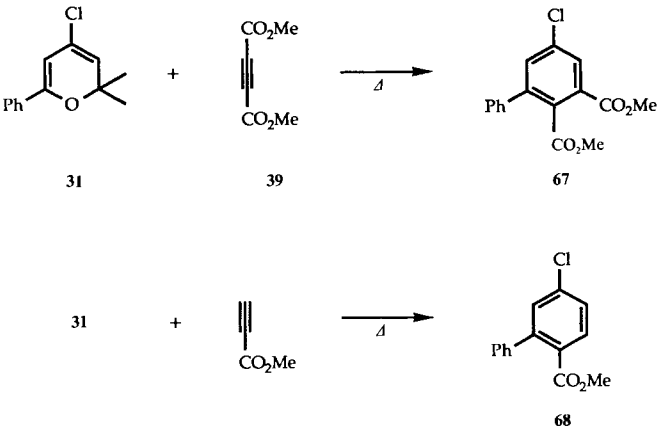
Strong support for the concerted mechanism is furnished by the fact, that 4-chloro-2*H*-pyran **31** (*Scheme 7*) cleanly undergoes the CAE reaction with acetylene **39** or methyl propiolate in purely thermal reactions upon heating at 80° (*Scheme 13*).

On the other hand it was mentioned earlier (*Chapt. 3.1*) that the silyl enol ether derived from **22** (R^1 = Ph, R^2 = Me) reacts in '*Mukaiyama*' fashion with *Michael* acceptors such as, *e.g.*, with 1,1-bis(benzenesulfonyl)ethene (**65**) to yield the 3-substituted 2,3-dihydro-2,2-dimethyl-4*H*-pyran-4-one **66** in 96% yield (*Scheme 5*).

---

[2]) The use of 2.5 equiv. of (t-Bu)$_2C_5H_3N$ and excess of enolizing reagent ($R^7R^8{}_2SiOTf$, Me_3OBF_4, or isopropenyl acetate) accelerates the formation of **VIII** by trapping the liberated acetone as its enol ethers or enol acetate **XX**, thus prohibiting an undesired transenolization from **IV–VI** to acetone.

Scheme 13



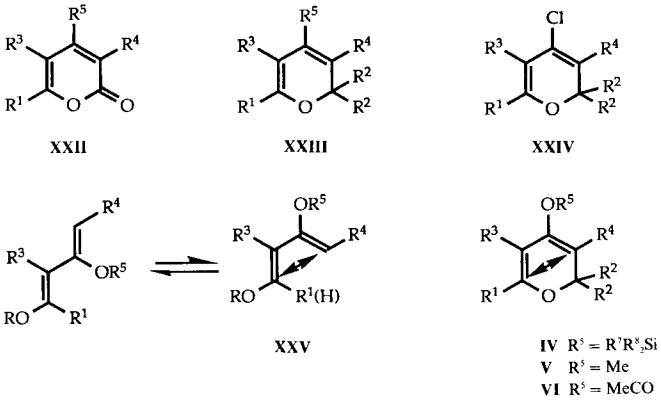
Furthermore, it should be noted, that the CAE reactions of **II** seem to be restricted to R^2 = Me, since **24** (R^1 = Ph, R^2 = i-Pr) did not undergo the expected CAE reaction, presumably for steric reasons. In addition, it should be noted that the corresponding diene of **3** (R^1 = H, R^2 = Me) prepared by *Method E* was not stable at 0°.

5. Conclusions. – In this paper, we described a general high-yield synthesis of substituted 2,2-dialkyl-2,3-dihydro-4*H*-pyran-ones of type **II** and **III** (*Scheme 1*) by acid-catalyzed cyclization of the corresponding acetylenic ketones **I**. Moreover, we have investigated the scope and limitations of the highly regioselective CAE reactions of the *in situ*-prepared electron-rich silyl enol ethers **IV** ($R^5 = R^7R^8{}_2Si$), enol ethers **V** (R^5 = Me), and enol acetates **VI** (R^5 = MeCO) (*Scheme 2*) of **II** and **III** with electron-poor acetylenes **VII**. In these reactions, the highly substituted aromatic compounds of type **VIII** and **IX** (*Schemes 2, 8, 10,* and *11*) are formed in good-to-excellent yields (*Table 3*). This reaction is especially interesting for R^1 = Ar, where highly substituted biaryls **VIII** and **IX** (R^1 = Ar) are obtained. This methodology thus offers a novel route to biologically interesting biaryl-derived natural products [8]. In addition, we present reaction mechanisms for the formation of the compounds of type **II** (or **III**; *Scheme 6*) and their CAE reactions with electron-poor acetylenes **VII** (*Schemes 11* and *12*).

A comparison of the reactivities of the corresponding 2*H*-pyran-2-ones **XXII** [6] [7], 2*H*-pyrans **XXIII** [5], 4-chloro-2*H*-pyrans **XXIV**, and the *in situ*-prepared electron-rich dienes **IV**–**VI** in the CAE reactions with electron-poor acetylenes of type **VII** reveals roughly the following order: **IV** > **V** ≈ **VI** > **XXIV** > **XXIII** > **XXII** (*Scheme 14*).

In conclusion, the *in situ*-prepared electron-rich dienes of type **IV**–**VI** derived from the readily available 2,2-dialkyl-2,3-dihydro-4*H*-pyran-4-ones **II** or **III** should be regarded as cyclic, conformationally restricted analogues of the '*Danishefsky* dienes' **XXV** [12] (*Scheme 14*). Their increased reactivities in *Diels-Alder*-type reactions with electron-poor acetylenes **VII** can be attributed to the facts, that in the cyclic dienes **IV** the s-*cis*-conformation is fixed and the distance between the terminal sp^2 C-atoms of the diene system is shortened compared to the acyclic dienes **XXV**, and for these reasons, they are more 'transition state like'. Finally, since the CAE reactions of **IV** work best when there are bulky substituents R^1 (*e.g.* R^1 = Ar, *t*-Bu) and the '*Danishefsky* dienes' **XXV**

Scheme 14



work best when R^1 = H, OR, these dienes are complementary. The use of the *in situ*-prepared electron-rich dienes of type **IV–VI** and **XXIV** in natural product synthesis will be reported in due course.

The author would like to thank his colleagues from the Central Research Units (CRU), *F. Hoffmann-La Roche AG*, for IR (Mr. *A. Bubendorf*), NMR (Dr. *W. Arnold*), mass spectra (Dr. *W. Vetter* and Mr. *W. Meister*), and elemental anylses (Dr. *W. Dirscherl* and Dr. *Müller*). He also thanks Prof. Dr. *H.-J. Hansen*, Dr. *Max Schmid*, Prof. Dr. *K. Müller* (CRU), Dr. *A. Knierzinger* (CRU), Prof. Dr. *J. E. Baldwin*, Dr. *C. J. Stankovic*, and especially Dr. *Rudolf Schmid* (CRU) for their fruitful discussions.

Experimental Part

General. All reactions with air- or moisture-sensitive reactants and solvents were carried out in oven- or flame-dried glassware under a positive pressure of dry Ar. Reaction solvents and liquid reagents were purified by distillation shortly before use. THF was distilled under Ar from Na with benzophenone ketyl as indicator. CH_2Cl_2 was distilled from powdered CaH_2. All other reactants were 'reagent-grade' unless described otherwise. Di(*tert*-butyl)pyridine ($(t\text{-Bu})_2C_5H_3N$), dimethyl(thexyl)silyl trifluoromethanesulfonate (Me_2(Th)SiOTf), (*tert*-butyl)-dimethylsilyl trifluoromethanesulfonate ($(t\text{-Bu})Me_2SiOTf$), triisopropylsilyl trifluoromethanesulfonate ($(i\text{-Pr})_3SiOTf$), trimethylsilyl trifluoromethanesulfonate (Me_3SiOTf), and *N*-bromosuccinimide (NBS) were all from *Fluka*. Anal. TLC: 2.5 × 10 cm precoated TLC plates, SiO_2 *60F-254*, layer thickness 0.25 mm (*E. Merck & Co.*, Darmstadt, FRG). Flash chromatography (FC): *E. Merck* SiO_2 *60* (230–400 mesh ASTM); according to [15]. M.p.: *Büchi-SMP-20* apparatus; uncorrected. IR: *Nicolet-7199-FT-IR* spectrometer; solids in KBr pellets, liquids as thin films; characteristic bands in cm^{-1}. ^{1}H-NMR: *Bruker-AC-250* apparatus, at 250 MHz; in $CDCl_3$; TMS as internal standard; chemical shifts of signal centres and ranges in ppm (δ), *J* in Hz.

1. General Methods. – *Method A.* To a stirred soln. of acetylenic alcohol **X** (10.0 mmol) in THF (30 ml) was added (i-Pr)MgCl (2M in THF; 10.5 ml, 21.0 mmol) at 0°. The mixture was stirred under Ar at r.t. for 5 h, a soln. of *N*-methoxy-*N*-methylamide **XI** (10.0 mmol) in THF (10 ml) added at −40°, and the mixture stirred for 12 h at r.t. and poured into a mixture of ice (20 g), 1M aq. NaH_2PO_4 (50 ml), and AcOEt (50 ml). After vigorous stirring for 30 min, the aq. layer was extracted with AcOEt (2 × 50 ml), the combined org. fraction washed with sat. brine (100 ml) and evaporated, and the residue purified by FC (150 g, SiO_2, Et_2O/hexane 1:1) and dried under reduced pressure, affording acetylenic ketone **I** as slightly yellow oil.

Method B. To a stirred soln. of acetylenic alcohol **X** (10.0 mmol) in THF (30 ml) was added at 0° (i-Pr)MgCl (2M in THF; 10.5 ml, 21.0 mmol). The mixture was stirred under Ar at r.t. for 5 h, a soln. of aldehyde **XII** (10.0 mmol) in THF (10 ml) added at −40°, and the mixture stirred for 30 min at −40° and for 2 h at 0° and poured

into a mixture of ice (20 g), sat. NH_4Cl soln. (50 ml) and AcOEt (50 ml). The aq. layer was extracted with AcOEt (2 × 50 ml) and the combined org. fraction washed with sat. brine (100 ml), dried ($MgSO_4$), and evaporated. The residue was dissolved in CH_2Cl_2 (15 ml) and added to a mechanically stirred suspension of MnO_2 (26 g) in CH_2Cl_2 (50 ml) at 0°. The mixture was stirred for 1 h at 0° and for 30 min at r.t. and filtered through $MgSO_4$, the filtrate evaporated, and the resulting residue purified as described in *Method A*.

Method C. To a stirred soln. of acetylenic ketone **I** (10.0 mmol) in CH_2Cl_2 (50 ml) was slowly added at 0° 33% HBr/AcOH soln. (2.75 ml). The mixture was stirred for 30 min at 0° and for 4–10 h at r.t. and poured into ice (50 g), H_2O (100 ml), and CH_2Cl_2 (50 ml). The aq. phase was extracted with CH_2Cl_2 (2 × 50 ml), the combined org. fraction dried ($MgSO_4$) and evaporated, the residue purified by FC (150 g, SiO_2, Et_2O/hexane 1:1), and the pyranone **II** crystallized or further purified by bulb-to-bulb distillation as indicated.

Method D. To a stirred soln. of pyranone **II** (10.0 mmol) in $CHCl_3$ (50 ml) was added slowly NBS (2.37 g, 10.5 mmol) at 0°. The mixture was stirred for 6 h at r.t. and poured into H_2O (100 ml) and CH_2Cl_2 (50 ml), the org. layer dried ($MgSO_4$) and evaporated, and the residue purified by FC (150 g, SiO_2, Et_2O/hexane 2:3) affording **III** R^3 = Br) as colourless crystals after recrystallization from AcOEt/hexane.

Method E. To a stirred soln. of **II** or **III** (1.0 mmol), $(t\text{-Bu})_2C_5H_3N$ (0.48 g, 2.5 mmol), and acetylene **VII** (1.0–6.0 mmol) in $CHCl_3$ (2.5 ml) was slowly added $R^7R^8{}_2SiOTf$ (2.2–2.3 mmol) under Ar. The mixture was stirred for 2 h at 0° and at r.t. as indicated and poured into a mixture of ice (10 g), sat. $NaHCO_3$ soln. (5 ml), and Et_2O (10 ml). The aq. layer was extracted with Et_2O (2 × 10 ml), the combined org. fraction extracted with sat. brine (10 ml), dried ($MgSO_4$), and evaporated, and the excess of **VII** (where possible) removed by bulb-to-bulb distillation under reduced pressure. The residue was purified by FC (30 g SiO_2) as indicated: **VIII** as colourless oils.

Method F. To a stirred soln. of **III** (1.0 mmol), $(t\text{-Bu})_2C_5H_3N$ (0.42 g, 2.2 mmol), and acetylene **VII** (1.0–3.0 mmol) in $CHCl_3$ (2.5 ml) was added at −30° freshly distilled Me_3SiOTf (0.46 ml, 2.5 mmol). The mixture was stirred for 30 min at 0° and at r.t. as indicated and poured into a mixture of MeOH (0.5 ml), 2N aq. HCl (5 ml), ice (5 g) and Et_2O (10 ml). The aq. layer was extracted with AcOEt (2 × 50 ml), the combined org. fraction dried ($MgSO_4$) and evaporated, the excess of **VII** and $(t\text{-Bu})_2C_5H_3N$ removed by bulb-to-bulb destillation under reduced pressure, the residue purified by FC (35 g SiO_2) as indicated, and the product **IX** crystallized from AcOEt/hexane.

2. Substituted Acetylenic Ketones of Type I. – 2.1. *5-Hydroxy-5-methylhex-2-ynal Diethyl Acetal* (**2**) [16]. A stirred soln. of **1** [9] (3.0 g, 30.56 mmol) in THF (150 ml) was treated according to *Method A* with diethyl phenyl orthoformate [16] (**12**; 7.68 ml, 1.3 equiv.) and stirred for 12 h at 45°. The mixture was poured into a mixture of ice (50 g), 2N aq. NaOH (100 ml), and Et_2O (200 ml). The org. layer was extracted with 2N aq. NaOH (2 × 75 ml), dried ($MgSO_4$), and evaporated. The residue was purified by FC (SiO_2 400 g), Et_2O/hexane 3:2 to yield, after bulb-to-bulb distillation under reduced pressure, 4.40 g (71.9%) of **2**. Colorless liquid. B.p. 150°/0.07 mbar. IR (film): 2976*m*, 2886*w*, 2242*m*, 1449*w*, 1361*w*, 1329*w*, 1150*m*, 1082*w*, 1051*s*, 1006*w*, 908*w*. ^{1}H-NMR ($CDCl_3$, 250 MHz): 5.29 (*t*, *J* = 1.6, H–C(1)); 3.8–3.55 (*m*, $(CH_3CH_2O)_2CH$); 2.45 (*d*, *J* = 1.6, 2 H–C(4)); 1.86 (br. *s*, OH); 1.43 (*s*, 2 CH_3–C(5)); 1.24 (*t*, *J* = 7.1, $(CH_3CH_2O)_2CH$). MS: 199 (< 1, $[M - H]^+$), 155 (18), 97 (56), 98 (58), 69 (39), 68 (50), 59 (100), 43 (61). Anal. calc. for $C_{11}H_{20}O_3$ (200.28): C 65.97, H 10.07; found: C 65.98, H 10.20.

2.2. *6-Hydroxy-6-methylhept-3-yn-2-one* (**13**). From **1** (5.0 g, 50.94 mmol) and **5** [17] (5.25 g, 50.94 mmol) according to *Method A:* 4.36 g (61.1%) of **13**. Colourless oil. IR (film): 3429*m* (br.), 2975*m*, 2212*s*, 1672*s*, 1418*w*, 1361*m*, 1361*m*, 1235*s*, 1149*w*, 967*w*, 906*w*. ^{1}H-NMR ($CDCl_3$, 250 MHz): 2.56 (*s*, 2 H–C(5)); 2.36 (*s*, 3 H–C(1)); 2.02 (*s*, OH); 1.35 (*s*, 2 CH_3–C(6)). MS: 125 (2, $[M - CH_3]^+$), 82 (47), 59 (100), 43 (75).

2.3. *5-Hydroxy-5-methylhex-2-ynophenone* (**14**) [2] [3]. From **1** (5.94 g, 60.54 mmol) and **6** [17] (10.0 g, 60.54 mmol) according to *Method A:* 11.08 g (90.4%) of **14**. Colourless oil [3].

2.4. *5-Hydroxy-5-isopropyl-6-methylhept-2-ynophenone* (**15**). From **4** (5.0 g, 32.4 mmol; prepared analogously to [9]) and **6** [17] (5.35 g, 32.4 mmol) according to *Method A:* 7.40 g (88.4%) of **15**. Slighthly yellow oil. IR (film): 3500*w* (br.), 2968*m*, 2879*w*, 2199*m*, 1640*s*, 1599*w*, 1448*w*, 1314*m*, 1267*s*, 1175*w*, 702*s*. ^{1}H-NMR ($CDCl_3$, 250 MHz): 8.2–8.1, 7.65–7.45 (2*m*, 5 arom. H); 2.73 (*s*, 2 H–C(4)); 2.25–2.05 (*m*, 2 $(CH_3)_2CH_2$); 1.47 (br. *s*, OH); 1.07, 1.03 (2*d*, *J* = 6.9, 2 $(CH_3)_2CH$). MS: 258 (< 1, M^+), 215 (31), 145 (37), 144 (100), 115 (49), 105 (30), 71 (57), 43 (47). Anal. calc. for $C_{17}H_{22}O_2$ (258.36): C 79.03, H 8.58; found: C 78.37, H 8.75.

2.5. *7-Hydroxy-2,2,7-trimethyloct-4-yn-3-one* (**16**). From **1** (3.0 g, 30.6 mmol) and **8** [17] (4.45 g, 30.6 mmol) according to *Method A:* 4.18 g (75%) of **16**. Slightly yellow oil. IR (film): 3424*w* (br.), 2990*s*, 2934*w*, 2210*m*, 1668*s*, 1478*m*, 1365*w*, 1277*w*, 1156*s*, 945*m*, 904*w*. ^{1}H-NMR ($CDCl_3$, 250 MHz): 2.59 (*s*, 2 H–C(4)); 2.0–1.5 (br. *s*, OH); 1.37 (*s*, 2 CH_3–C(7)); 1.21 (*s*, $(CH_3)_3C$). MS: 167 (2, $[M - CH_3]^+$), 124 (20), 81 (23), 67 (40), 59 (100), 57 (61), 43 (32), 41 (29). Anal. calc. for $C_{11}H_1H_{18}O_2$ (182.26): C 72.49, H 9.95; found: C 72.18, H 9.85.

2.6. *Methyl 6-Hydroxy-6-methyl-2-oxohept-3-ynoate* (**17**). From **1** (7.80 g, 79.5 mmol) and a freshly prepared soln. of methyl glyoxylate (**9**; 10.5 g, 0.119 mol) in THF (100 ml) according to *Method B.* FC (SiO_2 (400 g),

Et_2O/hexane 1:1) gave 8.93 g (61%) of **17**. Slightly yellow oil. IR (film): 3523*m*, 3426*m*, 2977*m*, 2214*s*, 1745*s*, 1684*s*, 1438*w*, 1276*m*, 1198*m*, 1162*s*, 1002*m*, 906*w*, 800*w*. ^{1}H-NMR ($CDCl_3$, 250 MHz): 3.93 (*s*, $COOCH_3$); 2.68 (*s*, 2 H–C(5)); 2.00 (br. *s*, OH); 1.40 (*s*, 2 CH_3–C(6)). MS: 125 (11, $[M - (CH_3)_2CO]^+$), 67 (54), 59 (100), 43 (34), 41 (12), 39 (12), 31 (18).

2.7. *Ethyl 7-Hydroxy-7-methyl-3-oxooct-4-ynoate* (**18**). From **1** (3.92 g, 39.9 mmol) and *ethyl 3-chloro-3-oxopropanoate* (**10**; *Fluka*; 2.5 ml, 19.15 mmol) according to *Method A*. FC (SiO_2 (250 g), AcOEt/hexane 1:3 → 1:1) gave 1.85 g (43.7%) of **18**. Slightly yellow oil. IR (film): 3452*w*, 2979*m*, 2214*m*, 1741*s*, 1678*s*, 1615*m*, 1467*w*, 1373*m*, 1324*m*, 1252*s*, 1176*m*, 1145*m*, 1032*m*. ^{1}H-NMR ($CDCl_3$, 250 MHz): 11.89 (*s*, OH, *ca.* 10% enol form); 5.32 (*s*, H–C(2), *ca.* 10% enol form); 4.22 (*q*, $J = 7.9$, CH_3CH_2O); 3.58 (*s*, 2 H–C(2)); 2.58 (*s*, 2 H–C(6)); 1.36 (*s*, 2 CH_3–C(7)); 1.27 (*t*, $J = 7.9$, CH_3CH_2O). MS: 154 (9, $[M - (CH_3)_2CO]^+$), 126 (41), 67 (38), 66 (38), 59 (100), 43 (42).

2.8. *5-Hydroxy-1-(2-methoxyphenyl)-5-methylhex-2-yn-1-one* (**19**). From **1** (3.5 g, 35.66 mmol) and *2-methoxybenzaldehyde* (**11**; *Fluka*; 4.86 g, 35.66 mmol) according to *Method B*. FC (SiO_2, Et_2O/hexane 2:1) gave 5.55 g (67%) of **19**. Pale yellow oil. IR (film): 3433*m* (br.), 2973*m*, 2936*w*, 2213*m*, 1635*s*, 1594*s*, 1486*s*, 1463*m*, 1434*m*, 1380*w*, 1303*m*, 1243*s*, 1164*m*, 1134*m*, 1020*m*, 920*m*, 758*m*. ^{1}H-NMR ($CDCl_3$, 250 MHz): 8.0–7.95, 7.55–7.5, 7.1–7.0 (3*m*, 4 arom. H); 3.93 (*s*, CH_3O); 2.65 (*s*, 2 H–C(4)); 1.39 (2 CH_3–C(5)). MS: 232 (2, M^+), 174 (55), 77 (19), 59 (100), 43 (14).

3. 2,2-Dialkyl-2,3-dihydro-4*H*-pyran-4-ones of Type II and III. – 3.1. *2,3-Dihydro-2,2-dimethyl-4*H*-pyran-4-one* (**3**) [18]. From **2** (1.0 g; 4.99 mmol) according to *Method C*. Bulb-to-bulb distillation under reduced pressure gave 560 mg (89%) of **3**. Slightly red liquid. B.p. 110°/18 Torr. IR (film): 3054*w*, 2980*m*, 1675*s*, 1595*s*, 1466*w*, 1410*m*, 1371*m*, 1324*w*, 1281*s*, 1173*m*, 1038*s*, 984*w*, 886*m*, 781*w*. ^{1}H-NMR ($CDCl_3$, 250 MHz): 7.23 (*d*, $J = 6.1$, H–C(6)); 5.39 (*d*, $J = 6.1$, H–C(5)); 2.53 (*s*, 2 H–C(3)); 1.44 (*s*, 2 CH_3–C(2)). MS: 126 (33, M^+), 111 (21), 71 (83), 56 (100), 41 (69). Anal. calc. for $C_7H_{10}O_2$ (126.16): C 66.64, H 7.99; found: C 66.81, H 8.30.

3.2. *2,3-Dihydro-2,2,6-trimethyl-4*H*-pyran-4-one* (**20**) [1]. From **13** (4.32 g, 30.8 mmol) according to *Method C*. Bulb-to-bulb distillation under reduced pressure gave 3.75 g (86.8%) of **20**. Colorless liquid. B.p. 70°/0.05 mbar. IR (film): 2979*w*, 2903*w*, 1667*s*, 1611*s*, 1437*w*, 1393*s*, 1359*m*, 1250*m*, 1156*m*, 1097*w*, 1016*m*, 990*m*, 882*w*, 800*w*. ^{1}H-NMR ($CDCl_3$, 250 MHz): 5.30 (*s*, H–C(5)); 2.43 (*s*, 2 H–C(3)); 1.97 (*s*, CH_3–C(6)); 1.42 (*s*, 2 CH_3–C(2)). MS: 140 (27, M^+), 125 (37), 85 (100), 69 (22), 56 (71), 43 (74), 41 (55). Anal. calc. for $C_8H_{12}O_2$ (140.18): C 68.55, H 8.63; found: C 68.31, H 8.84.

3.3. *5-Bromo-2,3-dihydro-2,2,6-trimethyl-4*H*-pyran-4-one* (**21**). From **20** (300 mg, 2.14 mmol) according to *Method D*. After recrystallization, 405 mg (86.4%) of **21**. M.p. 60–62°. IR (KBr): 2967*w*, 1673*s*, 1576*s*, 1374*m*, 1332*m*, 1272*w*, 1235*m*, 1168*m*, 1094*w*, 1002*m*, 570*m*. ^{1}H-NMR ($CDCl_3$, 250 MHz): 2.67 (*s*, 2 H–C(3)); 2.26 (*s*, CH_3–C(6)); 1.44 (*s*, 2 CH_3–C(2)). MS: 220, 218 (19, M^+), 205, 203 (60), 165, 163 (28), 56 (59), 43 (100). Anal. calc. for $C_8H_{11}BrO_2$ (219.08): C 43.86, H 5.06, Br 36.47; found: C 43.75, H 5.01, Br 36.92.

3.4. *2,3-Dihydro-2,2-dimethyl-6-phenyl-4*H*-pyran-4-one* (**22**) [2] [3]. From **14** (11.00 g, 53.32 mmol) according to *Method C*. FC (SiO_2, AcOEt/hexane 1:1) gave 9.60 g (87.3%) of **22**. White solid. M.p. 36–37°. Spectra: identical to those described in [3].

3.5. *5-Bromo-2,3-dihydro-2,2-dimethyl-6-phenyl-4*H*-pyran-4-one* (**23**). From **22** (2.05 g, 10.14 mmol) according to *Method D*. After recrystallization, 2.64 g (92.6%) of **23**. M.p. 98–99°. IR (KBr): 2990*w*, 1674*s*, 1604*w*, 1559*w*, 1488*w*, 1447*w*, 1374*w*, 1335*m*, 1233*w*, 1070*m*, 995*m*, 760*m*, 695*m*. ^{1}H-NMR ($CDCl_3$, 250 MHz): 7.7–7.65, 7.5–7.4 (2 *m*, 5 arom. H); 2.83 (*s*, 2 H–C(3)); 1.56 (*s*, 2 CH_3–C(2)). MS: 282, 280 (9, M^+), 267, 265 (22), 227, 225 (12), 105 (100), 77 (38). Anal. calc. for $C_{13}H_{13}BrO_2$ (281.15): C 55.54, H 4.66, Br 28.42; found: C 55.33, H 4.80, Br 28.38.

3.6. *2,3-Dihydro-2,2-diisopropyl-6-phenyl-4*H*-pyran-4-one* (**24**). From **15** (3.68 g, 14.25 mmol) according to *Method C*: 3.38 g (91.8%) of **24** as pale yellow oil, which solidified upon standing. M.p. 36–37°. IR (KBr): 3057*w*, 2975*m*, 2878*w*, 1648*s*, 1599*s*, 1570*m*, 1448*m*, 1381*s*, 1264*m*, 1060*w*, 1015*w*, 981*m*, 871*m*. ^{1}H-NMR ($CDCl_3$, 250 MHz): 7.8–7.7, 7.55–7.4 (2 *m*, 5 arom. H); 5.93 (*s*, H–C(5)); 2.62 (*s*, 2 H–C(3)); 2.29 (*sept.* $J = 6.9$, 2 $(CH_3)_2CH$); 1.05, 0.98 (2 *d*, $J = 6.9$, 2 $(CH_3)_2CH$). MS: 258 (12, M^+), 215 (16), 147 (51), 138 (100), 105 (72), 77 (23), 71 (43), 69 (60), 43 (42), 41 (44). Anal. calc. for $C_{17}H_{22}O_2$ (258.36): C 79.03, H 8.58; found: C 79.10, H 8.54.

3.7. *5-Bromo-2,3-dihydro-2,2-diisopropyl-6-phenyl-4*H*-pyran-4-one* (**25**). From **24** (2.78 g, 10.76 mmol) according to *Method D*. After recrystallization, 3.44 g (94.8%) of **25**. M.p. 71.5–72.5°. IR (KBr): 2982*w*, 2935*w*, 2876*w*, 1665*s*, 1652*s*, 1498*w*, 1443*w*, 1350*m*, 1324*w*, 1095*w*, 1025*m*, 989*m*, 681*m*. ^{1}H-NMR ($CDCl_3$, 250 MHz): 7.75–7.65, 7.55–7.4 (2 *m*, 5 arom. H); 2.88 (*s*, 2 H–C(3)); 2.28 (*sept.* $J = 6.9$, 2 $(CH_3)_2CH$); 1.04, 1.02 (2 *d*, $J = 6.9$, 2 $(CH_3)_2CH$). MS: 336 (3, M^+), 295, 293 (30), 257 (52), 227, 225 (33), 105 (100), 71, 69 (43), 55 (37), 43 (95). Anal. calc. for $C_{17}H_{21}BrO_2$ (337.26): C 60.54, H 6.28, Br 23.69; found: C 60.45, H 6.25, Br 23.57.

3.8. *6-(*tert*-Butyl)-2,3-dihydro-2,2-dimethyl-4*H*-pyran-4-one* (**26**) [10]. From **16** (3.08 g, 16.90 mmol) according to *Method C*: 2.80 g (91%) of **26** as pale yellow oil, which solidified upon standing. M.p. 36–37°. IR (KBr):

2958*m*, 1666*w*, 1587*m*, 1492*s*, 1454*m*, 1436*m*, 1282*s*, 1244*s*, 1177*s*, 1072*m*, 1029*m*, 830*m*. ^{1}H-NMR ($CDCl_3$, 250 MHz): 5.40 (*s*, H–C(5)); 2.43 (*s*, 2 H–C(3)); 1.41 (*s*, 2 CH_3–C(2)); 1.14 (*s*, $(CH_3)_3C$). MS: 182 (15, M^+), 127 (38), 69 (40), 57 (100), 43 (53), 41 (12). Anal. calc. for $C_{11}H_{18}O_2$ (182.26): C 72.49, H 9.95; found: C 72.40, H 10.11.

3.9. *Methyl 3,4-Dihydro-2,2-dimethyl-4-oxo-2*H*-pyran-6-carboxylate* (**27**) [19]. From **17** (1.30 g, 7.06 mmol) according to *Method C* (18 h at r. t.). FC (SiO_2 (50 g), Et_2O/hexane 1:1) and crystallization from Et_2O/hexane gave 870 mg (66.9%) of **27**. Pale yellow crystals. M.p. 67° ([19]: 68°). IR (KBr): 2981*w*, 2955*w*, 1733*s*, 1674*s*, 1610*m*, 1441*m*, 1393*m*, 1373*m*, 1279*s*, 1173*w*, 1078*m*, 993*m*, 866*m*. ^{1}H-NMR ($CDCl_3$, 250 MHz): 6.21 (*s*, H–C(5)); 3.88 (*s*, $COOCH_3$); 2.55 (*s*, 2 H–C(3)); 1.50 (*s*, 2 CH_3–C(2)). MS: 184 (8, M^+), 129 (21), 125 (36), 69 (100), 57 (27), 56 (65), 41 (31).

3.10. *Ethyl 3,4-Dihydro-2,2-dimethyl-4-oxo-2*H*-pyran-5-acetate* (**28**). From **18** (980 mg, 4.61 mmol) according to *Method C*. FC (SiO_2 (50 g), AcOEt/hexane 1:2) gave 710 mg (72.6%) of **28**. Pale yellow oil. IR (film): 2981*m*, 2905*w*, 1740*s*, 1670*s*, 1615*s*, 1465*w*, 1391*m*, 1324*m*, 1251*m*, 1177*m*, 1151*m*, 1030*m*, 992*m*. ^{1}H-NMR ($CDCl_3$, 250 MHz): 5.40 (*s*, H–C(5)); 4.19 (*q*, J = 7.5, CH_3CH_2O); 3.23 (*s*, $CH_2COOCH_2CH_3$); 2.48 (*s*, 2 H–C(3)); 1.44 (*s*, 2 CH_3–C(2)); 1.28 (*t*, J = 7.5, CH_3CH_2O). MS: 212 (4, M^+), 197 (12), 157 (12), 115 (16), 69 (100), 56 (46), 55 (56), 43 (50), 41 (58), 39 (54).

3.11. *2,3-Dihydro-2,2-dimethyl-6-(2-methoxyphenyl)-4*H*-pyran-4-one* (**29**). From **19** (5.40 g, 23.2 mmol) according to *Method C*. FC (SiO_2 (150 g), Et_2O/hexane 2:1) gave 5.25 g (96.3%) of **29** as pale yellow oil which solidified upon standing. M.p. 30–31°. IR (film): 2977*w*, 1657*s*, 1604*s*, 1568*m*, 1491*m*, 1462*m*, 1366*s*, 1280*m*, 1244*s*, 1167*s*, 1040*m*, 1020*m*, 760m. ^{1}H-NMR ($CDCl_3$, 250 MHz): 7.7–7.65 (*m*, 1 arom. H); 7.45–7.35 (*m*, 1 arom. H); 7.05–6.9 (*m*, 2 arom. H); 6.23 (*s*, H–C(5)); 3.87 (*s*, CH_3O); 2.59 (*s*, 2 H–C(3)); 1.53 (*s*, 2 CH_3–C(2)). MS: 232 (16, M^+), 217 (10), 137 (100), 105 (12), 77 (14). Anal. calc. for $C_{14}H_{16}O_3$ (232.28): C 72.39, H 6.94; found: C 72.18, H 6.99.

3.12. *Ethyl 3,4-Dihydro-2,2-dimethyl-4-oxo-6-phenyl-2*H*-pyran-5-carboxylate* (**30**) [1]. To a stirred soln. of ethyl 2-benzoylacetate (*Aldrich*; 10.0 g, 52.08 mmol) in THF (150 ml) was added a soln. of (i-Pr)MgCl (2 M in THF; 28.6 ml) at −60°. The mixture was stirred for 1 h at 0°, 3,3-dimethylacryloyl chloride (*Aldrich*; 6.17 g, 52.02 mmol) added at 0°, and the mixture stirred for 6 h at 40°, cooled to r. t., and quenched with sat. NH_4Cl soln. (100 ml), ice (100 g), and Et_2O (200 ml). The aq. phase was extracted with Et_2O (2 × 100 ml), the comb. org. fraction extracted with sat. brine (150 ml), dried ($MgSO_4$), and evaporated, and the residue chromatographed (SiO_2 (450 g), AcOEt/hexane 1:1) and recrystallized from AcOEt/hexane: 10.80 g (75.7%) of **30**. Colorless crystals. M.p. 78.5–79.5°. IR (KBr): 2975*w*, 2902*w*, 1722*s*, 1675*m*, 1571*m*, 1374*s*, 1258*m*, 1141*m*, 1086*s*, 704*w*. ^{1}H-NMR ($CDCl_3$, 250 MHz): 7.6–7.35 (*m*, 5 arom. H); 4.07 (*q*, J = 7.2, CH_3CH_2O); 2.67 (*s*, 2 H–C(3)); 1.58 (*s*, 2 CH_3–C(2)); 0.99 (*t*, J = 7.2, CH_3CH_2O). MS: 274 (4, M^+), 105 (100), 83 (18), 77 (50), 56 (19), 51 (18), 41 (20). Anal. calc. for $C_{16}H_{18}O_4$ (274.32): C 70.06, H 6.61; found: C 69.85, H 6.36.

3.13. *4-Chloro-2,2-dimethyl-6-phenyl-2*H*-pyran* (**31**). To a stirred soln. of 650 mg (3.21 mmol) of **22** in CH_2Cl_2 (8 ml) was added at 0° 1 drop of DMF and 0.41 ml (4.87 mmol) of freshly destilled oxalyl chloride. The mixture was stirred under Ar for 45 min at 0° and then evaporated and the residue purified by FC (SiO_2 (40 g), Et_2O/hexane 1:5): 680 mg (96%) of **31**. Pale yellow oil (which turned slightly red in the freezer). IR (film): 3088*w*, 3062*w*, 2978*w*, 2930*w*, 1634*s*, 1569*m*, 1492*m*, 1442*m*, 1360*m*, 1303*m*, 1197*w*, 1148*m*, 1048*s*, 1024*m*, 784*m*, 749*s*. ^{1}H-NMR ($CDCl_3$, 250 MHz): 7.65–7.6 (*m*, 2 arom. H); 7.4–7.35 (*m*, 3 arom. H); 5.78, 5.30 (2 *d*, J = 1.6, H–C(3), H–C(5)); 1.48 (*s*, 2 CH_3–C(2)). MS: 220 (5, M^+), 207 (34), 205 (100), 105 (48), 77 (47), 51 (16), 43 (21).

4. Carbonyl-Alkyne Exchange Reactions of *in situ*-Prepared Dienes of Type IV–VI. – 4.1. *5-{[(tert-Butyl)dimethylsilyl]oxy}biphenyl-2-yl Phenyl Ketone* (**33**). From **22** (500 mg, 2.47 mmol), **32** (420 mg, 3.23 mmol); prepared according to [3], and (*t*-Bu)Me_2SiOTf (1.36 ml, 5.92 mmol) according to *Method E* (1.5 h at r.t.). FC (SiO_2 (80 g), Et_2O/hexane 1:8), gave 930 mg (96.8%) of **33**. Colorless oil. IR (film): 3028*w*, 2931*m*, 2857*w*, 1683*m*, 1597*s*, 1558*w*, 1480*m*, 1045*w*, 1310*m*, 1259*s*, 1215*m*, 910*s*, 833*s*, 693*s*. ^{1}H-NMR ($CDCl_3$, 250 MHz): 7.65–7.6 (*m*, 2 arom. H); 7.5–7.35 (*m*, 2 arom. H); 7.3–7.1 (*m*, 7 arom. H); 6.95–6.85 (*m*, 2 arom. H); 1.01 (*s*, *t*BuSi); 0.26 (*s*, Me_2Si). MS: 388 (20, M^+), 331 (53), 105 (100), 77 (27).

4.2. *5-[(Triisopropylsilyl)oxy]biphenyl-2-yl Phenyl Ketone* (**34**). From **22** (300 mg, 1.48 mmol), **32** (250 mg, 1.92 mmol), and (i-Pr)$_3$SiOTf (0.42 ml, 3.40 mmol) according to *Method E* (2 h at r.t.). FC (SiO_2 (50 g), Et_2O/hexane 1:10) gave 560 mg (90.4%) of **34**. Colorless oil. IR (film): 3029*m*, 2944*m*, 2867*m*, 1663*m*, 1597*s*, 1555*m*, 1482*m*, 1402*w*, 1312*m*, 1280*s*, 1216*s*, 941*m*, 882*m*, 789*m*, 695*s*. ^{1}H-NMR ($CDCl_3$, 250 MHz): 7.65–7.55 (*m*, 2 arom. H); 7.5–7.35 (*m*, 2 arom. H); 7.3–7.1 (*m*, 7 arom. H); 7.0–6.9 (*m*, 2 arom. H); 1.4–1.2 (*m*, J = 6.7, $((CH_3)_2CH)_3Si$); 1.14 (*d*, J = 6.7, $((CH_3)_2CH)_3Si$). MS: 430 (9, M^+), 387 (30), 105 (100), 77 (19).

4.3. *5-Hydroxybiphenyl-2-yl Phenyl Ketone* (**35**). *a*) A soln. of **34** (400 mg, 0.96 mmol) in MeOH (3 ml) and 2N aq. HCl (1 ml) was stirred for 3 h at 80° in a sealed tube, cooled to r.t., and mixed with H_2O (5 ml) and AcOEt

(10 ml). The aq. phase was extracted with AcOEt (2 × 5 ml), the comb. org. fraction dried ($MgSO_4$) and evaporated, and the residue crystallized from Et_2O/hexane: 245 mg (93%) of **35**. Colorless crystals. M.p. 179–180°. IR (KBr): 3292*m* (br.), 3024*w*, 1635*s*, 1595*s*, 1481*w*, 1437*w*, 1318*w*, 1289*s*, 1219*w*, 887*m*, 746*m*. 698*s*. ^{1}H-NMR ($CDCl_3$, 250 MHz): 7.7–7.55 (*m*, 2 arom. H); 7.5–7.35 (*m*, 2 arom. H); 7.35–7.05 (*m*, 7 arom. H); 6.9–6.8 (*m*, 2 arom. H); 6.41 (*s*, OH). MS: 274 (58, $M^{+\cdot}$), 273 (45), 197 (100), 105 (21), 77 (31). Anal. calc. for $C_{19}H_{14}O_2$ (274.32): C 83.29, H 5.14; found: C 83.15, H 5.08.

b) From **22** (700 mg, 3.46 mmol), **32** (585 mg, 4.50 mmol), and Me_3SiOTf (1.60 ml, 8.65 mmol) according to *Method F* (24 h at r.t.). Recrystallization from AcOEt/hexane gave 794 mg (83.7%) of **35**. Colorless crystals. M.p. 179–180°.

4.4. *3-Methyl-5-[(triisopropylsilyl)oxy]biphenyl-2-yl Phenyl Ketone* (**37**). From **22** (300 mg, 1.48 mmol), *but-2-ynophenone* (**36**; prepared according to *Method A*; 336 mg, 2.33 mmol), and (i-Pr)$_3$SiOTf (0.92 ml, 3.41 mmol) according to *Method E*. Chromatography (SiO_2 (50 g), Et_2O/hexane 1:10) gave 625 mg (95%) of **37**. Colorless oil. IR (film): 3031*w*, 2944*m*, 2867*m*, 1666*m*, 1595*s*, 1467*m*, 1335*s*, 1266*m*, 1195*s*, 995*w*, 926*w*, 881*m*, 792*m*, 693*m*. ^{1}H-NMR ($CDCl_3$, 250 MHz): 7.6–7.5, 7.4–7.3, 7.3–7.05, 6.85–6.75 (4*m*, 12 arom. H); 2.21 (*s*, CH_3); 1.4–1.2 (*m*, J = 6.6, 3 $(CH_3)_2CH$); 1.14 (*d*, J = 6.6, 3 $(CH_3)_2CH$). MS: 444 (10, $M^{+\cdot}$), 401 (20), 105 (100), 77 (22).

4.5. *5-Hydroxy-3-methylbiphenyl-2-yl Phenyl Ketone* (**38**). A soln. of **37** (580 mg, 1.30 mmol) in EtOH (4.5 ml) and 2N aq. HCl (1 ml) was treated for 4.5 h at 80° in a sealed tube, cooled to r.t., and mixed with ice (5 g) H_2O (5 ml), and Et_2O (10 ml). The org. phase was dried ($MgSO_4$) and evaporated and the residue purified by FC (SiO_2 (50 g), Et_2O/hexane 1:1) and recrystallization from AcOEt/hexane: 350 mg (93.4%) of **38**. Colorless crystals. M.p. 148.0–148.5°. IR (KBr): 3309*m* (br.), 3024*w*, 2932*w*, 1638*s*, 1595*m*, 1576*m*, 1497*w*, 1447*w*, 1319*m*, 1279*s*, 1187*m*, 1099*w*, 916*w*, 858*w*, 748*m*, 699*m*. ^{1}H-NMR ($CDCl_3$, 250 MHz): 7.6–6.55 (*m*, 2 arom. H); 7.45–7.3 (*m*, 1 arom. H); 7.3–7.05 (*m*, 7 arom. H); 6.8–6.7 (*m*, 2 arom. H); 5.44 (*s*, OH); 2.20 (*s*, CH_3). MS: 288 (70, $M^{+\cdot}$) 287 (100, $[M-1]^+$), 211 (73). Anal. calc. for $C_{20}H_{16}O_2$ (288.35): C 83.31, H 5.59; found: C 83.15, H 5.68.

4.6. *Dimethyl 5-[(Triisopropylsilyl)oxy]biphenyl-2,3-dicarboxylate* (**40**). From **22** (300 mg, 1.48 mmol), *dimethyl acetylenedicarboxylate* (**39**; *Fluka;* 0.55 ml, 4.48 mmol)) and (i-Pr)$_3$SiOTf (0.92 ml, 3.41 mmol) according to *Method E* (30 h at r.t.). FC (SiO_2 (50 g), Et_2O/hexane 1:5) gave 450 mg (68.7%) of **40**. Pale yellow oil. IR (film): 2947*m*, 2868*m*, 1735*s*, 1595*m*, 1466*m*, 1432*m*, 1344*s*, 1267*s*, 1239*s*, 1168*s*, 1112*w*, 1066*w*, 1011*m*, 884*w*, 781*w*. ^{1}H-NMR ($CDCl_3$, 250 MHz): 7.44 (*d*, J = 2.5, 1 arom. H); 7.45–7.3 (*m*, 5 arom. H); 7.03 (*d*, J = 2.5, 1 arom. H); 3.90, 3.64 (2*s*, 2 $COOCH_3$); 1.4–1.2 (*m*, J = 6.7, 3 $(CH_3)_2CH$); 1.11 (*d*, J = 6.7, 3 $(CH_3)_2CH$). MS: 442 (11, $M^{+\cdot}$), 411 (10), 399 (28), 367 (100), 339 (28). Anal. calc. for $C_{25}H_{34}O_5Si$ (442.63): C 67.84, H 7.74; found: C 67.46, H 8.00.

4.7. *Dimethyl 5-Hydroxybiphenyl-2,3-dicarboxylate* (**41**). A soln. of 370 mg (0.84 mmol) of **40** in MeOH (2.5 ml) and 2N aq. HCl (0.5 ml) was stirred for 3 h at 80° in a sealed tube, cooled to r.t., and mixed with ice (5 g), H_2O (5 ml), and AcOEt (10 ml). The org. layer was dried ($MgSO_4$) and evaporated and the residue purified by FC (SiO_2 (30 g), AcOEt/hexane 1:1) and recrystallization from Et_2O: 225 mg (93.6%) of **41**. Colorless crystals. M.p. 105–107°. IR (KBr): 3306*m* (br.), 3057*w*, 3021*w*, 2908*w*, 1720*s*, 1700*s*, 1600*m*, 1428*m*, 1339*m*, 1301*m*, 1268*m*, 1232*m*, 1121*w*, 1064*w*, 999*w*, 948*w*, 870*w*, 779*w*, 760*w*, 702*m*. ^{1}H-NMR ($CDCl_3$, 250 MHz): 7.35–7.25 (*m*, 5 arom. H); 7.32, 6.91 (2*d*, J = 2.5, 2 arom. H); 6.69 (*s*, OH); 3.84, 3.64 (2*s*, 2 $COOCH_3$). MS: 286 (34, $M^{+\cdot}$), 256 (19), 255 (100), 223 (10), 139 (14). Anal. calc. for $C_{16}H_{14}O_5$ (286.28): C 67.13, H 4.93; found: C 66.83, H 5.09.

4.8. *Ethyl 5-[(Triisopropylsilyl)oxy]biphenyl-2-carboxylate* (**43**). From **22** (300 mg, 1.48 mmol), *ethyl propiolate* (**42**; *Fluka;* 1.5 ml, 14.8 mmol), and (i-Pr)$_3$SiOTf (1.0 ml, 3.71 mmol) according to *Method E* (18 h at 60°). FC (SiO_2 (50 g), Et_2O/hexane 1:20) gave 335 mg (56.8%) of **43**. Pale yellow oil. IR (film): 3060*w*, 3038*w*, 2944*m*, 2868*m*, 1711*s*, 1598*s*, 1561*w*, 1484*m*, 1386*w*, 1364*w*, 1313*m*, 1280*s*, 1245*m*, 1217*s*, 1127*m*, 1099*w*, 1020*w*, 940*m*, 882*m*, 778*w*, 696*m*. ^{1}H-NMR ($CDCl_3$, 250 MHz): 7.80 (*d*, J = 7.9, 1 arom. H); 7.45–7.25 (*m*, 5 arom. H); 6.95–6.85 (*m*, 2 arom. H); 4.05 (*q*, J = 7.1, $COOCH_2CH_3$); 1.4–1.2 (*m*, 3 $(CH_3)_2CH$); 1.10 (*d*, J = 6.7, 3 $(CH_3)_2CH$); 0.96 (*t*, J = 7.1, $COOCH_2CH_3$). MS: 398 (13, $M^{+\cdot}$), 356 (27), 355 (100), 327 (30), 299 (52), 211 (28), 127 (26).

4.9. *Ethyl 5-Hydroxybiphenyl-2-carboxylate* (**44**) [13]. A stirred soln. of **43** (300 mg, 0.75 mmol) in EtOH (5 ml) and 2N aq. HCl (1 ml) was treated for 7 h at 75° in a sealed tube, cooled to r.t., and mixed with ice (5 g), H_2O) (5 ml), and AcOEt (10 ml). The org. phase was dried ($MgSO_4$) and evaporated and the residue purified by FC (SiO_2 (40 g), Et_2O/hexane 1:2) and recrystallization from Et_2O: 180 mg (99%) of **44**. M.p. 72.5–73.5°. IR (KBr): 3389*s*, 3056*w*, 2987*w*, 2900*w*, 1672*s*, 1600*s*, 1472*w*, 1437*w*, 1390*w*, 1364*w*, 1295*s*, 1221*s*, 1135*m*, 1023*w*, 865*w*, 768*m*, 704*m*. ^{1}H-NMR ($CDCl_3$, 250 MHz): 7.82 (*d*, J = 7.8, 1 arom. H); 7.4–7.2 (*m*, 5 arom. H); 6.85–6.75 (*m*, 2 arom. H); 5.89 (br. *s*, OH); 4.05 (*q*, J = 7.1, $COOCH_2CH_3$); 0.98 (*t*, J = 7.1, $COOCH_2CH_3$). MS: 242 (31, $M^{+\cdot}$), 197 (100), 141 (13), 139 (11), 115 (12). Anal. calc. for $C_{15}H_{14}O_3$ (242.27): C 74.36, H 5.82; found: C 74.43, H 5.96.

4.10. *Methyl 2-Benzoyl-5-{[(tert-butyl)dimethylsilyl]oxy}biphenyl-3-carboxylate* (**46**). From **22** (500 mg, 2.47 mmol), *methyl 4-oxo-4-phenylbut-2-ynoate* [20] (**45**; 490 mg, 2.60 mmol); and (*t*-Bu)Me_2SiOTf (1.25 ml, 5.43 mmol) according to *Method E* (2 h at r.t.). FC (SiO_2 (70 g), Et_2O/hexane 1:3) and crystallization from Et_2O gave

1.08 g (98%) of **46**. White solid. M.p. 83–85°. IR (KBr): 3063*w*, 3003*w*, 2930*m*, 2857*m*, 1726*s*, 1671*m*, 1598*m*, 1440*m*, 1342*s*, 1285*m*, 1165*m*, 1011*m*, 945*m*, 835*s*, 699*m*. ^{1}H-NMR ($CDCl_3$, 250 MHz): 7.65–7.5 (*m*, 2 arom. H); 7.50 (*d*, *J* = 2.4, 1 arom. H); 7.45–7.35 (*m*, 1 arom. H); 7.35–7.2 (*m*, 2 arom. H); 7.16 (*s*, 5 arom. H); 7.04 (*d*, *J* = 2.4, 1 arom. H); 3.66 (*s*, $COOCH_3$); 1.02 (*s*, *t*-BuSi); 0.27 (*s*, Me_2Si). MS: 466 (45, M^+), 389 (74), 357 (100), 313 (30), 226 (19), 105 (54), 89 (49), 77 (55), 75 (38), 59 (31), 57 (22). Anal. calc. for $C_{27}H_{20}O_4Si$ (446.62): C 72.61, H 6.77; found: C 72.44, H 6.91.

4.11. *Methyl 2-Benzoyl-5-hydroxybiphenyl-3-carboxylate* (**47**). A suspension of **46** (550 mg, 1.23 mmol) in MeOH (5 ml) and 2N aq. HCl (1 ml) was stirred for 2 h at 75° (clear soln.), cooled to r.t., and mixed with ice (5 g), H_2O (5 ml), and AcOEt (10 ml). The org. phase was dried ($MgSO_4$) and evaporated and the residue crystallized from AcOEt/hexane: 370 mg (90.5%) of **47**. Colorless crystals. M.p. 152–153°. IR (KBr): 3368*m* (br.), 3089*w*, 3020*w*, 2956*w*, 1696*s*, 1671*s*, 1602*m*, 1580*m*, 1448*w*, 1351*m*, 1312*m*, 1263*s*, 1234*s*, 1186*m*, 1073*w*, 1002*w*, 925*w*, 772*w*, 708*m*. ^{1}H-NMR ($CDCl_3$, 250 MHz): 7.65–7.55 (*m*, 2 arom. H); 7.45 (*d*, *J* = 2.5, 1 arom. H); 7.45–7.35 (*m*, 1 arom. H); 7.3–7.25 (*m*, 2 arom. H); 7.12 (*s*, 5 arom. H); 7.0–6.95 (br. *s*, OH); 6.98 (*d*, *J* = 2.5, 1 arom. H); 3.58 (*s*, $COOCH_3$). MS: 332 (25, M^+), 255 (100), 105 (29), 77 (22). Anal. calc. for $C_{21}H_{16}O_4$ (332.36): C 75.89, H 4.85; found: C 75.61, H 5.03.

4.12. *2-Benzoyl-5-{[(*tert*-butyl)dimethylsilyl]oxy}biphenyl-3-carbaldehyde* (**49**). From **22** (180 mg, 0.89 mmol), *4,4-diethoxybut-2-ynophenone* [20] (**48**; 250 mg, 1.08 mmol), and (*t*-Bu)Me_2SiOTf (0.45 ml, 1.96 mmol) according to *Method E* (2 h at r.t.). FC (SiO_2 (40 g), Et_2O/hexane 1:15) gave 365 mg (98%) of **49**. Pale yellow oil. IR (film): 3060*w*, 2955*w*, 2930*w*, 2858*w*, 1665*m*, 1597*s*, 1463*w*, 1341*m*, 1263*s*, 1177*m*, 1128*m*, 1059*s*, 882*w*, 835*s*. ^{1}H-NMR ($CDCl_3$, 250 MHz): 9.90 (*s*, CHO); 7.6–7.1 (*m*, 12 arom. H); 1.03 (*s*, *t*-BuSi); 0.29 (*s*, Me_2Si). MS: 416 (33, M^+), 415 (100, $[M-1]^+$), 105 (27), 73 (33).

4.13. *2-Benzoyl-5-hydroxybiphenyl-3-carbaldehyde* (**50**). A soln. of **49** (310 mg, 0.74 mmol) in EtOH (4 ml) and 2N aq. HCl (2 ml) was stirred for 2 h at 65° in a sealed tube, cooled to r.t., and mixed with ice (5 g), H_2O (5 ml), and AcOEt (10 ml). The org. phase was dried ($MgSO_4$) and evaporated and the residue crystallized from AcOEt/hexane: 205 mg (91%) of **50**. Colorless crystals. M.p. 193.5–194.5°. IR (KBr): 3213*m* (br.), 3061*w*, 2925*w*, 2888*w*, 1675*s*, 1603*m*, 1575*m*, 1446*w*, 1330*m*, 1247*s*, 1176*m*, 1114*w*, 928*m*, 697*s*. ^{1}H-NMR ($CDCl_3$, 250 MHz): 9.87 (*s*, CHO); 7.65–7.55 (*m*, 2 arom. H); 7.5–7.35 (*m*, 2 arom. H); 7.3–7.1 (*m*, 8 arom. H); 6.06 (br. *s*, OH). MS: 302 (100, M^+), 273 (47), 257 (29), 197 (22), 105 (24), 77 (50). Anal. calc. for $C_{20}H_{24}O_3$ (302.33): C 79.46, H 4.67; found: C 79.64, H 4.64.

4.14. *6-Bromo-5-hydroxybiphenyl-2-yl Phenyl Ketone* (**51**). From **23** (350 mg, 1.24 mmol) and **32** (486 mg, 3.73 mmol) according to *Method F* (24 h at r.t.). FC (SiO_2 (40 g), Et_2O/hexane 3:2) gave 85 mg (24%) of recovered **23** and 197 mg (45%; 59% based on recovered **23**) of **51**. Pale yellow solid. M.p. 155–156°. IR (KBr): 3449*m* (br.), 3059*w*, 1652*s*, 1595*m*, 1551*m*, 1435*w*, 1313*s*, 1267*s*, 1236*m*, 1136*w*, 1073*w*, 702*m*. ^{1}H-NMR ($CDCl_3$, 250 MHz): 7.6–7.5, 7.5–7.35, 7.3–7.05 (3*m*, 12 arom. H); 6.03 (br. *s*, OH). MS: 354, 352 (60, M^+), 277, 275 (100), 196 (65), 168 (31), 113 (23), 105 (88), 77 (98), 51 (24). Anal. calc. for $C_{19}H_{13}BrO_2$ (353.22): C 64.61, H 3.71, Br 22.62; found: C 64.65, H 3.65, Br 22.32.

4.15. *2-(*tert*-Butyl)-4-{[(*tert*-butyl)dimethylsilyl]oxy}-6-methylbenzophenone* (**52**). From **26** (400 mg, 2.19 mmol), **36** (633 mg, 4.39 mmol), and (*t*-Bu)Me_2SiOTf (1.11 ml, 4.82 mmol) according to *Method E* (4 h at r.t.). FC (SiO_2 (50 g), AcOEt/hexane 1:20) gave 310 mg (49%) of recovered **36** and 620 mg (74%) of **52**. Pale yellow oil. IR (film): 3060*w*, 2930*w*, 2859*w*, 1671*m*, 1597*s*, 1469*m*, 1307*s*, 1251*s*, 1212*w*, 1157*m*, 1120*w*, 841*s*, 781*m*, 717*m*. ^{1}H-NMR ($CDCl_3$, 250 MHz): 8.3–7.6 (br. *m*, 2 arom. H); 7.6–7.35 (br. *m*, 3 arom. H); 6.87, 6.56 (2*d*, *J* = 2.3, 2 arom. H); 1.94 (*s*, CH_3); 1.21 (*s*, *t*-BuC); 1.02 (*s*, *t*-BuSi); 0.25 (*s*, Me_2Si). MS: 382 (17, M^+), 325 (31), 105 (100), 77 (16).

4.16. *2-(*tert*-Butyl)-4-hydroxy-6-methylbenzophenone* (**53**). A soln. of **52** (400 mg, 1.05 mmol) in EtOH (5 ml) and 2N aq. HCl (2 ml) was stirred for 1 h at 75° in a sealed tube, cooled to r.t., and mixed with ice (5 g), H_2O (5 ml), and AcOEt (10 ml). The org. phase was dried ($MgSO_4$) and evaporated and the residue purified by FC (SiO_2 (40 g), Et_2O/hexane 2:3) and recrystallization from Et_2O/hexane: 265 mg (94%) of **53**. Colorless crystals. M.p. 150–152°. IR (KBr): 3380*m*, 3060*w*, 2959*m*, 2867*m*, 1651*s*, 1605*s*, 1585*s*, 1448*m*, 1365*w*, 1302*s*, 1267*s*, 1248*s*, 1210*m*, 1116*w*, 984*w*, 859*w*, 719*m*. ^{1}H-NMR ($CDCl_3$, 250 MHz): 8.3–7.6 (br. *m*, 2 arom. H); 7.6–7.35 (*m*, 3 arom. H); 6.89, 6.55 (2*d*, *J* = 2.4, 2 arom. H); 5.21 (br. *s*, OH); 1.94 (*s*, CH_3); 1.22 (*s*, *t*-Bu). MS: 268 (14, M^+), 253 (16), 191 (100), 105 (38), 77 (41). Anal. calc. for $C_{18}H_{20}O_2$ (268.36): C 80.56, H 7.51; found: C 80.45, H 7.23.

4.17. *Dimethyl 3-(*tert*-Butyl)-5-[(triisopropylsilyl)oxy]benzene-1,2-dicarboxylate* (**54**). From **26** (300 mg, 1.65 mmol) **39** (*Fluka;* 1.22 ml, 9.93 mmol), and (i-Pr)$_3$SiOTf (1.02 ml, 3.80 mmol) according to *Method E* (24 h at 60°). FC (SiO_2 (50 g), Et_2O/hexane 1:4) gave 420 mg (60.2%) of **54**. Pale yellow oil. IR (film): 2948*s*, 2868*m*, 1738*s*, 1596*s*, 1463*m*, 1433*m*, 1318*s*, 1229*s*, 1125*m*, 1010*m*, 883*m*. ^{1}H-NMR ($CDCl_3$, 250 MHz): 7.31, 7.18 (2*d*, *J* = 2.5, 2

arom. H); 3.87, 3.86 (2*s*, 2 $COOCH_3$); 1.37 (*s*, *t*-Bu); 1.35–1.15 (*m*, $((CH_3)_2CH)_3Si$); 1.10 (*d*, $J = 8.7$, $((CH_3)_2CH)_3Si$). MS: 422 (7, M^+), 391 (9), 379 (16), 347 (100), 319 (16), 59 (20).

4.18. *Dimethyl 3-(*tert*-Butyl)-5-hydroxybenzene-1,2-dicarboxylate* (**55**). A soln. of **54** (320 mg, 0.76 mmol) in MeOH (3 ml) and 2N aq. HCl (1 ml) was stirred for 3.5 h at 80° in a sealed tube, cooled to r.t., and mixed with ice (5 g), H_2O (5 ml), and AcOEt (10 ml). The org. layer was dried ($MgSO_4$) and evaporated and the residue crystallized from AcOEt/hexane: 185 mg (91.4%) of **55**. Colorless crystals. M.p. 119–120°. IR (KBr): 3381*m* (br.), 2960*w*, 1727*s*, 1702*s*, 1581*m*, 1430*m*, 1321*m*, 1261*s*, 1218*s*, 1130*m*, 1081*m*, 1000*w*, 951*w*, 881*w*. ^{1}H-NMR ($CDCl_3$, 250 MHz): 7.28, 7.16 (2*d*, $J = 2.6$, 2 arom. H); 5.46 (br. *s*, OH); 3.87, 3.85 (2*s*, 2 $COOCH_3$); 1.37 (*s*, *t*-Bu). MS: 266 (19, M^+), 235 (65), 219 (100), 203 (23). Anal. calc. for $C_{14}H_{18}O_5$ (266.29): C 63.15, H 6.81; found: C 62.85, H 6.54.

4.19. *5-{[Dimethyl(1,1,2-trimethylpropyl)silyl]oxy}-2′-methoxybiphenyl-2-yl Phenyl Ketone* (**56**). From **29** (500 mg, 2.15 mmol), **32** (364 mg, 2.80 mmol), and Me_2(Th)SiOTf (1.25 ml, 4.95 mmol) according to *Method E* (2 h at r.t.). FC (SiO_2 (50 g), Et_2O/hexane 1:10) and crystallization from EtOH/H_2O gave 840 mg (87.5%) of **56**. White needles. M.p. 94.5–95.5°. IR (KBr): 3063*w*, 3007*w*, 2960*m*, 2864*w*, 1663*s*, 1600*s*, 1557*m*, 1491*m*, 1450*w*, 1313*s*, 1258*s*, 1214*s*, 1026*w*, 940*m*, 827*s*, 709*m*. ^{1}H-NMR ($CDCl_3$, 250 MHz): 7.8–7.7 (*m*, 2 arom. H); 7.5–7.15 (*m*, 6 arom. H); 7.0–6.8 (*m*, 3 arom. H); 6.64 (*d*, $J = 8.0$, 1 arom. H); 3.39 (*s*, CH_3O); 1.74 (*sept.*, $J = 6.6$, $[(CH_3)_2CHC(CH_3)_2]Si$); 0.96 (*d*, $J = 6.6$, $[(CH_3)_2CHC(CH_3)_2]Si$); 0.97 (*s*, $[(CH_3)_2CHC(CH_3)_2]Si$); 0.29 (*s*, Me_2Si). MS: 446 (1, M^+), 415 (36), 361 (22), 331 (15), 105 (100), 77 (22). Anal. calc. for $C_{22}H_{34}O_3Si$ (446.66): C 75.29, H 7.67; found: C 75.38, H 7.56.

4.20. *5-Hydroxy-2′-methoxybiphenyl-2-yl Phenyl Ketone* (**57**). A soln. of **56** (670 mg, 1.50 mmol) in EtOH (5 ml) and 2N aq. HCl (2 ml) was stirred for 2.5 h at 80° in a sealed tube, cooled to r.t., and mixed with ice (5 g), H_2O (5 ml), and AcOEt (10 ml). The org. layer was dried ($MgSO_4$) and evaporated and the residue crystallized from Et_2O/hexane: 425 mg (93%) of **57**. Colorless crystals. M.p. 177.5–178.5°. IR (KBr): 3212*m* (br.), 3069*w*, 2965*m*, 2935*w*, 1624*m*, 1595*s*, 1585*m*, 1490*w*, 1431*m*, 1318*s*, 1290*w*, 1239*s*, 1179*w*, 939*w*, 750*w*, 750*m*, 705*m*. ^{1}H-NMR ($CDCl_3$, 250 MHz): 7.8–7.7 (*m*, 2 arom. H); 7.5–7.1 (*m*, 6 arom. H); 7.0–6.8 (*m*, 3 arom. H); 6.65 (*d*, $J = 8.0$, 1 arom. H); 5.52 (*s*, OH); 3.39 (*s*, CH_3O). MS: 304 (2, M^+), 274 (20), 273 (100), 105 (10), 77 (15). Anal. calc. for $C_{20}H_{16}O_3$ (304.35): C 78.93, H 5.10; found: C 78.79, H 5.44.

4.21. *Dimethyl 2′-Methoxy-5-[(triisopropylsilyl)oxy]biphenyl-2,3-dicarboxylate* (**58**). From **29** (360 mg, 1.55 mmol), **39** (*Fluka;* 0.95 ml, 7.73 mmol), and (i-Pr)$_3$SiOTf (0.96 ml, 3.57 mmol) according to *Method E* (16 h at 60°). FC (SiO_2 (50 g), Et_2O/hexane 1:3) gave 580 mg (79.2%) of **58**. Pale yellow oil. IR (film): 2947*m*, 2868*m*, 1735*s*, 1498*w*, 1463*m*, 1432*m*, 1342*s*, 1264*s*, 1246*s*, 1164*m*, 1122*m*, 1011*m*, 761*w*. ^{1}H-NMR ($CDCl_3$, 250 MHz): 7.4–7.25 (*m*, 2 arom. H); 7.2–7.15 (*m*, 1 arom. H); 7.0–6.9 (*m*, 3 arom. H); 3.86, 3.72 (2*s*, 2 $COOCH_3$); 3.59 (*s*, CH_3O); 1.4–1.2 (*m*, $((CH_3)_2CH)_3Si$); 1.10 (*d*, $J = 6.7$, $((CH_3)_2CH)_3Si$). MS: 472 (6, M^+), 397 (100), 369 (17), 59 (17).

4.22. *Dimethyl 5-Hydroxy-2′-methoxybiphenyl-2,3-dicarboxylate* (**59**). To a stirred soln. of **58** (530 mg, 1.12 mmol) in THF (5 ml) was added a soln. of $Bu_4NF \cdot 3H_2O$ (*Fluka;* 389 mg, 1.23 mmol) in THF (5 ml) at 0°. The mixture was stirred for 30 min at 0° and for 30 min at r.t., mixed with ice (5 g), H_2O (5 ml), and Et_2O (10 ml), the aq. layer extracted with AcOEt (2 × 5 ml), the combined org. fraction dried ($MgSO_4$) and evaporated, and the residue purified by FC (SiO_2 (30 g), Et_2O/hexane) and recrystallization from Et_2O/hexane: 319 mg (90%) of **59**. Colorless crystals. M.p. 161.5–162.5°. IR (KBr): 3384*m* (br.), 3076*m*, 2995*w*, 2945*w*, 1713*s*, 1612*m*, 1578*m*, 1500*m*, 1430*m*, 1352*m*, 1280*s*, 1265*s*, 1239*s*, 1195*m*, 1125*m*, 1063*w*, 1020*w*, 997*w*, 765*m*. ^{1}H-NMR ($CDCl_3$, 250 MHz): 7.35–7.25 (*m*, 2 arom. H); 7.2–7.1 (*m*, 1 arom. H); 7.0–6.8 (*m*, 3 arom. H); 5.73 (*s*, OH); 3.86, 3.72 (2*s*, 2 $COOCH_3$); 3.58 (*s*, CH_3O). MS: 316 (25, M^+), 285 (100), 256 (15), 241 (53), 225 (28), 197 (15), 69 (16). Anal. calc. for $C_{17}H_{16}O_6$ (316.31): C 64.55, H 5.10; found: C 64.58, H 5.04.

4.23. *Ethyl 6-Benzoyl-3-hydroxy-5-methylbiphenyl-2-carboxylate* (**60**). From **30** (300 mg, 1.09 mmol) and **36** (0.31 g, 2.18 mmol) according to *Method F* (5 h at r.t.). Crystallization from AcOEt/hexane gave 185 mg (47%) of **60**. Pale yellow solid. M.p. 104–106°. IR (KBr): 3028*w*, 2930*w*, 2861*w*, 1656*s*, 1575*m*, 1447*w*, 1397*w*, 1354*m*, 1309*m*, 1272*m*, 1235*s*, 1196*m*, 1074*s*, 693*m*. ^{1}H-NMR ($CDCl_3$, 250 MHz): 11.15 (*s*, OH); 7.55–7.35, 7.3–7.15, 7.1–6.75 (3*m*, 10 arom. H); 6.95 (*s*, H–C(3)); 3.90 (*q*, $J = 7.1$, $COOCH_2CH_3$); 2.20 (*s*, CH_3–C(4)); 0.63 (*t*, $J = 7.1$, $COOCH_2CH_3$). MS: 360 (60, M^+), 314 (100), 237 (43), 152 (20), 105 (69), 17 (67). Anal. calc. for $C_{23}H_{20}O_4$ (360.41): C 76.65, H 5.59; found: C 76.92, H 5.56.

4.24. *6-Ethyl 2,3-Dimethyl 5-{[Dimethyl(1,1,2-trimethylpropyl)silyl]oxy}biphenyl-2,3,6-tricarboxylate* (**61**). From **30** (500 mg, 1.82 mmol), **39** (*Fluka;* 2.23 ml, 18.16 mmol), and Me_2(Th)SiOTf (1.05 mmol, 4.19 mmol) according to *Method E* (60 h at 60°). FC (SiO_2 (80 g), Et_2O/hexane 1:5) gave 530 mg (58%) of **61**. Pale yellow oil. IR (film): 2955*m*, 2870*w*, 1735*s*, 1588*m*, 1463*m*, 1344*m*, 1299*m*, 1239*s*, 1179*m*, 1102*m*, 821*m*, 701*w*. ^{1}H-NMR ($CDCl_3$, 250 MHz): 7.44 (*s*, 1 arom. H); 7.4–7.2 (*m*, 5 arom. H); 3.95 (*q*, $J = 7.1$, $COOCH_2CH_3$); 3.90, 3.53 (2*s*, 2 $COOCH_3$); 1.71 (*sept.*, $J = 6.8$, $[(CH_3)_2CHC(CH_3)_2]Si$); 0.95–0.8 (*m*, $[(CH_3)_2CHC(CH_3)_2]Si$); 0.33 (*s*, Me_2Si). MS: 469 (6, $[M - CH_3O]^+$), 415 (60), 355 (100), 75 (30), 43 (24).

4.25. *6-Ethyl 2,3-Dimethyl 5-Hydroxybiphenyl-2,3,6-tricarboxylate* (**62**). To a stirred soln. of **61** (200 mg, 0.40 mmol) in THF (2 ml) was added a soln. of $Bu_4NF \cdot 3H_2O$ (*Fluka;* 139 mg, 0.44 mmol) in THF (1 ml) at 0°. The mixture was stirred for 30 min at 0° and for 30 min at r.t. and then mixed with ice (5 g), 2N aq. HCl (2 ml), and AcOEt (10 ml), the aq. phase extracted with AcOEt (2 × 5 ml), the combined org. fraction dried ($MgSO_4$) and evaporated, and the residue purified by FC (SiO_2 (15 g), Et_2O/hexane 2:1) and recrystallization from Et_2O/hexane: 130 mg (90.7%) of **62**. Colorless crystals. M.p. 100–102°. IR (KBr): 3295*m* (br.), 3090*w*, 3062*w*, 2980*w*, 2953*w*, 1726*s*, 1695*s*, 1589*m*, 1440*m*, 1418*m*, 1312*m*, 1227*s*, 1182*m*, 1107*m*, 1011*w*, 669*m*. ^{1}H-NMR ($CDCl_3$, 250 MHz): 11.04 (*s*, OH); 7.61 (*s*, 1 arom. H); 7.35–7.3 (*m*, 3 arom. H); 7.2–7.1 (*m*, 2 arom. H); 3.95 (*q*, $J = 7.2$, $COOCH_2CH_3$); 3.91, 3.47 (2*s*, 2 $COOCH_3$); 0.69 (*t*, $J = 7.2$, $COOCH_2CH_3$). MS: 358 (41, M^+), 312 (100), 281 (85), 280 (46), 252 (56), 105 (10), 77 (10). Anal. calc. for $C_{19}H_{18}O_7$ (358.35): C 63.68, H 5.06; found: C 63.68, H 5.18.

4.26. *Methyl 2-Benzoyl-5-methoxybiphenyl-3-carboxylate* (**63**). To a stirred suspension of Me_3OBF_4 (*Fluka;* 285 mg, 1.93 mmol) in dry CH_2Cl_2 (3 ml) was added under Ar (t-Bu)$_2C_5H_3N$ (425 mg, 2.22 mmol) and **22** (300 mg, 1.48 mmol) at 0°. The mixture was stirred for 3 h at r.t., followed by addition of **45** [20] (306 mg, 1.63 mmol) in small portions. The mixture was stirred for 18 h at r.t., mixed with ice (10 g), 2N aq. HCl (5 ml), and AcOEt (10 ml), the aq. layer extracted with AcOEt (2 × 5 ml), the combined org. fraction dried ($MgSO_4$) and evaporated, and the residue purified by FC (SiO_2 (50 g), Et_2O/hexane 2:5): 105 mg (35%) of recovered **22** and 290 mg (56.6%; 87% based on recovered **22**) of **63**. White solid. A sample was recrystallized from Et_2O/hexane. M.p. 124–125°. IR (KBr): 3060*w*, 3015*w*, 2948*w*, 1728*s*, 1672*s*, 1598*w*, 1443*w*, 1339*s*, 1262*m*, 1159*w*, 1074*w*, 1039*w*, 751*w*. ^{1}H-NMR ($CDCl_3$, 250 MHz): 7.65–7.55 (*m*, 3 arom. H); 7.45–7.35 (*m*, 1 arom. H); 7.3–7.2 (*m*, 2 arom. H); 7.17 (*s*, 5 arom. H); 7.09 (*d*, $J = 2.6$, 1 arom. H); 3.93 (*s*, $COOCH_3$); 3.66 (*s*, CH_3O). MS: 346 (27, M^+), 269 (100), 139 (11), 105 (22), 77 (35). Anal. calc. for $C_{22}H_{18}O_4$ (346.38): C 76.29, H 5.24; found: C 76.24, H 5.35.

4.27. *Dimethyl 5-Acetoxybiphenyl-2,3-dicarboxylate* (**64**). A stirred soln. of **22** (150 mg, 0.74 mmol), **39** (*Fluka;* 0.45 ml, 3.66 mmol), isopropenyl acetate (*Fluka;* 0.37 g, 3.70 mmol), and TsOH · $1H_2O$ (*Fluka;* 10 mg) in $CHCl_3$ (1 ml) was treated under Ar for 18 h at 75° in a sealed tube. The solvents were evaporated, and the residue was purified by FC (SiO_2 (20 g), AcOEt/hexane 1:4): 220 mg (90.5%) of **63**. Colorless oil. IR (KBr): 3060*w*, 3026*w*, 2952*w*, 1768*s*, 1731*s*, 1598*m*, 1435*m*, 1326*s*, 1268*s*, 1241*s*, 1200*s*, 1158*m*, 1112*m*, 1068*m*, 1017*m*, 702*m*. ^{1}H-NMR ($CDCl_3$, 250 MHz): 7.75 (*d*, $J = 2.4$, 1 arom. H); 7.45–7.35 (*m*, 5 arom. H); 7.31 (*d*, $J = 2.4$, 1 arom. H); 3.91, 3.67 (2*s*, 2 $COOCH_3$); 2.33 (*s*, AcO). MS: 328 (6, M^+), 286 (44), 255 (100), 195 (10), 43 (37). Anal. calc. for $C_{18}H_{16}O_6$ (328.22): C 65.85, H 4.91; found: C 65.78, H 5.17.

4.28. *3-[2,2-Bis(phenylsulfonyl)ethyl]-2,3-dihydro-2,2-dimethyl-6-phenyl-4*H*-pyran-4-one* (**66**). From **22** (400 mg, 1.98 mmol), *1,1-bis(phenylsulfonyl)ethene* (**65**; *Fluka;* 792 mg, 2.57 mmol) and (t-Bu)Me_2SiOTf (1.14 ml, 4.96 mmol) according to *Method E* (3 h at r.t.). FC (SiO_2 (80 g), AcOEt/hexane 1:1) and recrystallization from Et_2O/hexane gave 970 mg (96%) of **66**. White solid. M.p. 178.5–179.5°. IR (KBr): 3061*w*, 2980*w*, 2920*w*, 1650*s*, 1602*s*, 1570*m*, 1479*w*, 1370*m*, 1326*m*, 1156*s*, 1079*m*, 728*m*, 686*m*. ^{1}H-NMR ($CDCl_3$, 250 MHz): 8.15–8.0 (*m*, 2 arom. H); 7.8–7.35 (*m*, 13 arom. H); 5.53 (*s*, H–C(5)); 5.25–5.15 (*m*, $(PhSO_2)_2CHCH_2$); 3.05–2.9 (*m*, H–C(3)); 2.7–2.55, 2.35–2.2 (2*m*, $(PhSO_2)_2CHCH_2$); 1.54, 1.52 (2*s*, 2 CH_3–C(2)). MS: 495 (13, $[M - CH_3]^+$), 223 (89), 202 (83), 187 (87), 147 (62), 105 (89), 77 (100), 69 (46), 41 (36). Anal. calc. for $C_{27}H_{26}O_6S_2$ (510.62): C 63.51, H 5.13, S 12.56; found: C 63.43, H 5.14, S 12.35.

4.29. *Dimethyl 5-Chlorobiphenyl-2,3-dicarboxylate* (**67**). A stirred soln. of freshly prepared **31** (220 mg, 1.00 mmol) and **39** (*Fluka;* 1 ml) was heated under Ar for 2.5 h at 60° in a sealed tube. The excess of **39** was evaporated and the residue purified by FC (SiO_2 (30 g), Et_2O/hexane 1:4): 235 mg (77.1%) of **67**. Colorless oil. IR (film): 3060*w*, 3027*w*, 2950*w*, 1728*s*, 1667*w*, 1591*m*, 1433*m*, 1287*s*, 1243*m*, 1132*w*, 1107*m*, 1042*w*, 835*w*, 762*m*. ^{1}H-NMR ($CDCl_3$, 250 MHz): 7.98, 7.54 (2*d*, $J = 2.1$, 2 arom. H); 7.45–7.3 (*m*, 5 arom. H); 3.92, 3.66 (2*s*, 2 $COOCH_3$). MS: 304 (38, M^+), 275 (33), 273 (100), 241 (20). Anal. calc. for $C_{16}H_{13}ClO_4$ (304.73): C 63.06, H 4.03, Cl 11.63; found: C 62.85, H 4.29, Cl 11.51.

4.30. *Methyl 5-Chlorobiphenyl-2-carboxylate* (**68**). A stirred soln. of freshly prepared **31** (210 mg, 0.95 mmol) and methyl propiolate (*Fluka;* 1 ml) was heated under Ar for 24 h at 60°. The excess methyl propiolate was evaporated and the residue purified by FC (SiO_2 (25 g), Et_2O/hexane 1:10): 40 mg (19%) of recovered **31** and 140 mg (59.7%; 73.7% based on recovered **31**) of **68**. Colorless oil. IR (film): 3063*w*, 3030*w*, 3000*w*, 2951*w*, 1733*s*, 1582*m*, 1497*w*, 1452*w*, 1434*m*, 1422*m*, 1308*s*, 1265*s*, 1237*s*, 1201*m*, 1176*m*, 1122*m*, 1069*m*, 978*w*, 791*m*. ^{1}H-NMR ($CDCl_3$, 250 MHz): 7.85–7.8 (*m*, 1 arom. H); 7.45–7.35, 7.35–7.25 (2*m*, 7 arom. H); 3.63 (*s*, $COOCH_3$). MS: 246 (44, M^+), 213 (33), 215 (100), 152 (65), 76 (23). Anal. calc. for $C_{14}H_{11}ClO_2$ (246.69): C 68.16, H 4.49, Cl 14.37; found: C 67.83, H 4.30, Cl 14.25.

REFERENCES

[1] S. Gelin, R. Gelin, *Bull. Soc. Chim. Fr.* **1968,** 288.
[2] L. J. Vereshchagin, L. D. Gavrilov, E. I. Titova, L. G. Tikhonova, S. R. Buzilova, *Khim. Geterotsikl. Soedin.* **1967,** 1471.
[3] D. Obrecht, *Helv. Chim. Acta* **1989,** *72,* 447.
[4] A. Duperrier, M. Moreau, S. Gelin, J. Dreux, *Bull. Soc. Chim. Fr.* **1974,** 2207.
[5] R. G. Salomon, J. R. Burns, W. J. Dominic, *J. Org. Chem.* **1976,** *41,* 2918.
[6] T. Ziegler, M. Layh, F. Effenberger, *Chem. Ber.* **1987,** *120,* 1347.
[7] R. K. Dieter, W. H. Balke, J. R. Fishpaugh, *Tetrahedron* **1988,** *44,* 1915; F. Effenberger, T. Ziegler, *Chem. Ber.* **1987,** *120,* 1339.
[8] M. Sainsbury, *Tetrahedron* **1980,** *36,* 3327; H. J. Altenbach, *Nachr. Chem. Tech. Lab.* **1988,** *36,* 1324.
[9] L. Miginiac, *Ann. Chim. Fr.* **1961,** 1071.
[10] S. Gelin, R. Henry, *Bull. Soc. Chim. Fr.* **1975,** 305.
[11] S. Danishefsky, M. Bednarsky, T. Izawa, C. Maring, *J. Org. Chem.* **1984,** *49,* 2290: R. E. Ireland, D. Obrecht, *Helv. Chim. Acta* **1986,** *69,* 1273.
[12] S. Danishefsky, T. Kitahara, *J. Am. Chem. Soc.* **1974,** *96,* 7807; S. Danishefsky, *Acc. Chem. Res.* **1981,** *14,* 400.
[13] A. B. Smith III, S. W. Kilény, *Tetrahedron Lett.* **1985,** 4419.
[14] T. Mukaiyama, Y. Sagawa, S. Kobayashi, *Chem. Lett.* **1986,** 1821.
[15] C. Still, M. Kahn, A. Mitra, *J. Org. Chem.* **1978,** *43,* 2923.
[16] F. Barbot, P. Miginiac, *Bull. Soc. Chim. Fr.* **1983,** 41.
[17] S. Nahm, S. Weinreb, *Tetrahedron Lett.* **1981,** 3815.
[18] E. M. Kosower, T. S. Sörensen, *J. Org. Chem.* **1963,** *28,* 687.
[19] J. B. Tingle, L. Claisen, *Liebigs Ann. Chem.* **1896,** *291,* 111.
[20] M. Midland, D. Mc. Dowall, R. L. Hatch, A. Tramontano, *J. Am. Chem. Soc.* **1980,** *102,* 867.