Hypervalent iodine in organic synthesis: α-functionalization of carbonyl compounds

OM PRAKASH, NEENA SAINI, MADAN P. TANWAR,

Department of Chemistry, Kurukshetra University, Kurukshetra-132 119 (Haryana), India

and ROBERT M. MORIARTY

Department of Chemistry, University of Illinois at Chicago, P.O. Box 4348, Chicago IL 60680, USA

Reviewing the literature published up to February 1995

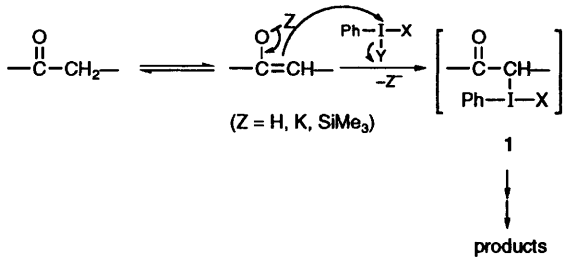
1 Introduction

Despite the fact that hypervalent iodine compounds have been known since 1886,[1] it is only comparatively recent that their versatility as reagents in organic synthesis has been recognized.[2–13] From 1980 onwards a surge of interest in the use of organo I^{III} reagents in organic synthesis has been observed, and these studies have been summarized in several reviews. One of the most interesting features of hypervalent iodine reagents is their use in the direct α-functionalization of ketones and of some other carbonyl compounds. Since α-functionalized ketones are extremely useful and versatile precursors in organic synthesis, their ready access via the iodine(III)-mediated approach has simplified many synthetic (and mechanistic) problems in organic chemistry. The first report of the α-functionalization of ketones was published by Mizukami *et al.*[14] who introduced a method for α-acetoxylation of ketones and β-diketones by the action of iodobenzene diacetate (IBD) and sulfuric acid (H_2SO_4). Later, Moriarty *et al.*[15] and Koser *et al.*[16] developed methods for the α-hydroxylation and α-tosyloxylation of ketones using IBD–KOH/MeOH and [hydroxy(tosyloxy)iodo]benzene (HTIB), respectively. Following these studies, the two reagents IBD and HTIB have gained significant importance in bringing about a wide variety of α-functionalizations, and this review summarizes recent work in this important area of synthesis.

The major accomplishments in the area of α-functionalization of carbonyl compounds can be classified according to the type of reagent system/substrate involved in the reactions. Therefore, for convenience, the subject matter in this article has been discussed in four parts: (i) the application of IBD–KOH/MeOH for α-hydroxylations of carbonyl compounds; (ii) α-sulfonyloxylations of carbonyl compounds using HTIB, [hydroxy(mesyloxy)iodo]benzene, *etc.* and their uses in preparing various α-functionalized carbonyl compounds; (iii) α-functionalizations of carbonyl compounds by oxidations of silyl enol ethers using iodosobenzene–boron trifluoride etherate; (iv) miscellaneous examples of α-functionalizations of carbonyl compounds, including the formation of

oxygen-containing heterocycles by intramolecular participation.

It is worth mentioning that a significant step in the mechanistic pathway for the oxidation reactions by hypervalent iodine described in this review, is the electrophilic addition of the hypervalent iodine reagent PH-I (X)-Y onto the enol form of the ketone/silyl enol ether/enolate, leading to intermediates of type **1** (**Scheme 1**). The intermediate **1** can then lead to the formation of various products via different routes depending upon the reaction conditions. Several such possibilities are illustrated in the discussion of results at appropriate places in the text.

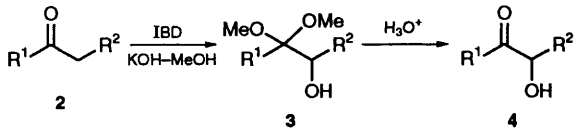


Scheme 1

2 α-Functionalizations of carbonyl compounds using iodobenzene diacetate (IBD)–KOH/MeOH

2.1 Formation of α-hydroxydimethylacetals: a useful route to α-hydroxyketones

Hypervalent iodine oxidations of enolizable ketones **2** using IBD–potassium hydroxide or sodium hydroxide provide an efficient route to α-hydroxydimethylacetals **3**. The acid hydrolyses of these acetals then lead to α-hydroxyketones **4** (**Scheme 2**).

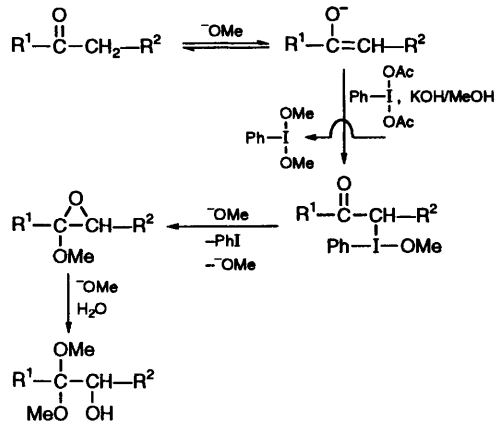


Scheme 2

Although the conversions **2** → **3** → **4** are quite general, some exceptions, where treatment of a ketone with IBD–KOH/MeOH does not give the expected acetals, have also been noted. For example, it has recently been found that 2,4-dihydroxyacetophenones undergo interesting rearrangement reactions leaving acetyl or enolizable ketonic groups unaffected.[17] Since the results of this reaction (**2** → **3**) covering the literature up to early 1986 have been reviewed earlier,[6] only the mechanism (**Scheme 3**) and newer applications (**Chart 1**) are presented here.

Some noteworthy features of the results presented in **Chart 1** are as follows:

(i) The oxidizing conditions work successfully on 'nitrogen' and 'sulfur' containing heterocyclic ketones[18] (**5** → **7**, via **6**) without affecting the hetero atoms.



Scheme 3

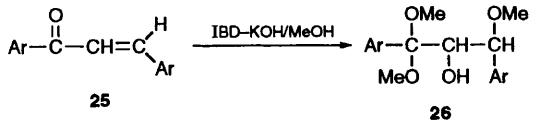
(ii) Tropan-3-one **8** on oxidation using IBD–KOH/MeOH gives **9** which upon acid hydrolysis produces 2α-hydroxytropan-3-one[19] (**10**). The oxidation of tropine with LTA is known to give the same compound, among other products.[27] Studies based on *X*-ray analysis[19(b)] finally proved that the reported compound **10** was in error.

(iii) The synthesis of the new chiral AB-synthon **19** for preparing the optically active anthracyclinones **20** was attained through a stereospecific nucleophilic addition of trimethylsilylethynylmagnesium chloride to the chiral 2-tetralone-1-acetal **18**.[22] The latter acetal was prepared via **17** by way of hypervalent iodine oxidation of the ketone **16**.

(iv) *Cis*-3-Hydroxyflavanones **23**, which are not widely known in the literature, are now available in a regio- and stereo-specific manner as shown in **Chart 1** (**f**).[23–25] This reaction is quite general, and is also applicable to chromanones[23] and 2-furylchromanones.[26]

2.2 Oxidations of α,β-unsaturated ketones

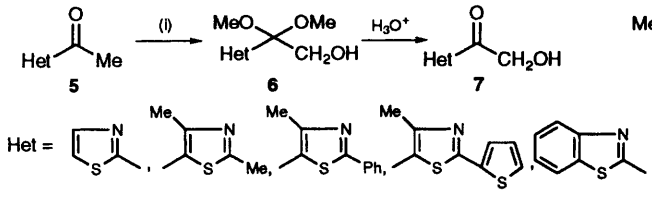
A particularly fascinating feature of the hypervalent iodine reagent in the presence of $^-$OMe ion is the oxidation of α,β-unsaturated ketones, which do not contain an enolizable ketone group. For instance, chalcones **25** on treatment with IBD–KOH/MeOH give, interestingly, α-hydroxy-β-methoxydimethylacetals[23] **26** (**Scheme 4**). This methodology has a distinct advantage as it can be employed to effect C(3)-hydroxylations of chromones, flavones, and α-naphthoflavones, which is an important reaction in flavonoid chemistry.[23,28,29]



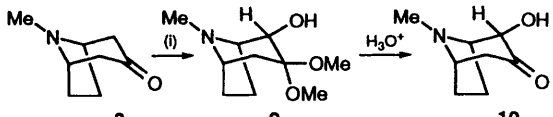
Scheme 4

The use of the reagent system IBD–KOH/MeOH becomes important in building oxygen-containing heterocyclic systems where intramolecular participation by a suitably placed hydroxyl group occurs (*vide infra*, section 5.3.1).

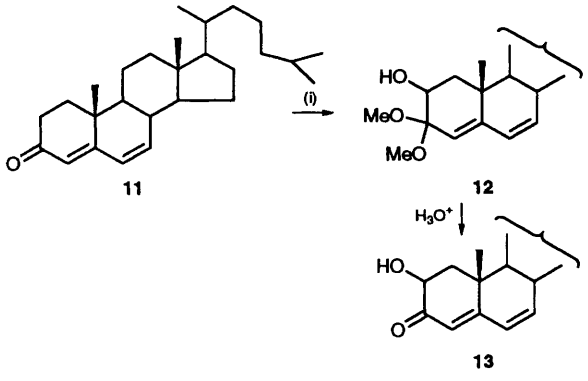
(a) α-Hydroxylations of thiazolyl and benzothiazolyl ketones[18]



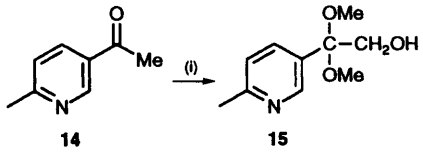
(b) Regio- and stereo-specific formation of 2α-tropan-3-one[19]



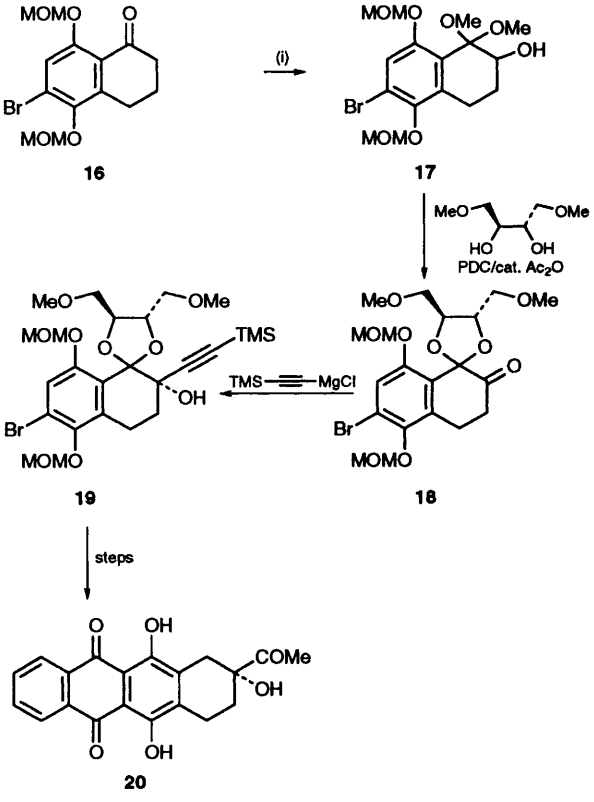
(c) α-Hydroxylations of some steroidal ketones [20]



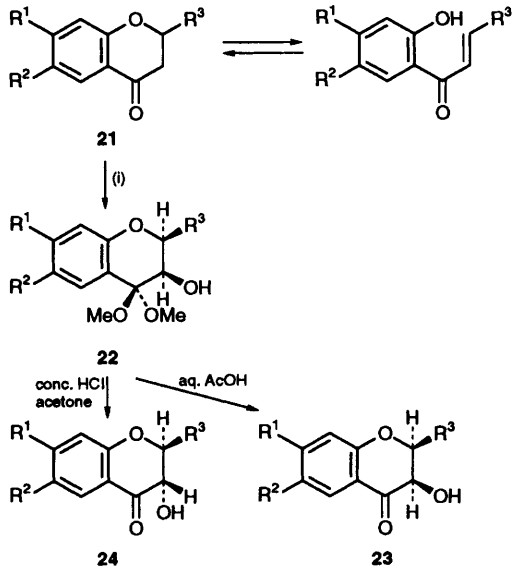
(d)[21]



(e) Asymmetric synthesis of anthracyclinones using chiral acetal[22]



(f) *cis* - and *trans* -3-Hydroxyflavanones, chromanones, and 2-furyl analogues[23-26]



R^1 = H, OMe
R^2 = H, Cl, Me
R^3 = Ph, substituted phenyl, 2-furyl

Reagent: (i) Iodobenzene diacetate(IBD)–KOH/MeOH

Chart 1

3 Direct α-sulfonyloxylations of carbonyl compounds and the preparation of other α-functionalizations via α-tosyloxyketones

3.1 α-Sulfonyloxylations of carbonyl compounds

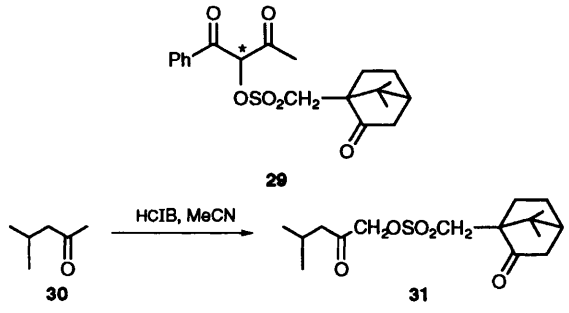
There is considerable interest in various α-sulfonyloxy carbonyl compounds because of their potential in organic synthesis[30] and in studies of their photochemical reactivity.[31] Approaches toward their preparation not requiring the availability of α-hydroxyketones and involving enolic ketone derivatives have been summarized.[30] The direct introduction of a tosyloxy or mesyloxy group to ketones and β-dicarbonyl compounds has been affected by using HTIB[16] or HMIB,[32,33] respectively in MeCN or CH_2Cl_2 (**Scheme 5**).

The reagents HTIB and HMIB can also be used when generated *in situ* from IBD-*p*-TsOH[34] and iodosobenzene–methanesulfonic acid,[35] respectively.

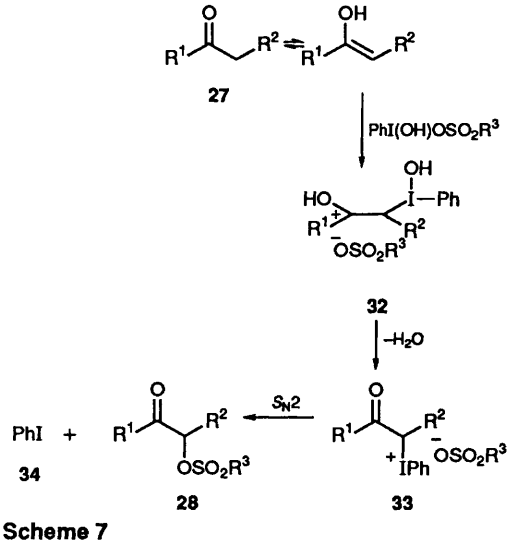
Varvoglis *et al.*[36] have employed a similar approach for obtaining various α-[(+)(10-camphorsulfonyl)]oxyketones by using [hydroxy{(+)10-camphorsulfonyl)oxy}iodo]benzene (HCIB), (**Scheme 5**).

β-Diketones, β-keto esters, and diethyl malonate also react with HCIB to give corresponding α-(+)10-camphorsulfonyloxylated derivatives.[36] In the case of benzoylacetone, the crude product **29** was determined to be a 3:1 mixture of diastereoisomers. However, an attempt to separate the diastereomers by chromatography resulted in isomerization thereby yielding a nearly 1:1 mixture[36] of the two diastereomers. An interesting feature of this reagent is the steric bulk of the camphorsulfonate ligand which allows the regioselective formation of the less hindered product, *e.g.* 4-methyl-2-pentanone **30** apparently gives only the C-1 camphorsulfonate[36] **31** (**Scheme 6**).

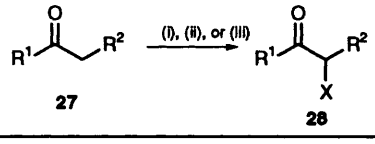
A general mechanistic scheme is shown in **Scheme 7**. Thus, the I^{III} intermediate **32** loses water to give the α-phenyliodonioketone sulfonate **33**. Nucleophilic addition of $^-OSO_2R^3$ at the α-carbon in **33** then affords the α-sulfonyloxylated product with the simultaneous expulsion of PhI (**34**). The validity of this mechanism is provided by the isolation of the proposed intermediate α-phenyliodoniosulfonates **33** from the reaction of β-diketones such as dimedone,[16] (α-thienoyl)trifluoroacetone,[37] and indane-1,3-dione[37] with HTIB in MeCN at room temperature.

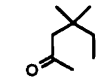
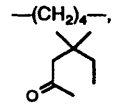
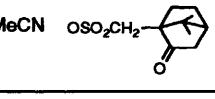


Scheme 6



Scheme 7



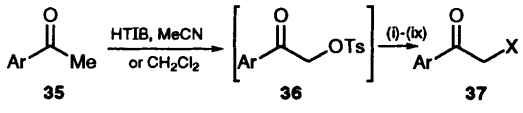
Condition	X	R^1	R^2	R^1R^2 (in cyclic ketones)	Ref.
(i) = HTIB, MeCN or CH_2Cl_2	OTs	alkyl, aryl, 2-thienyl, 2-benzo-thiazolyl	H, Me, Ph, COPh, COMe, $CO_2C_2H_5$	$-(CH_2)_4-$, 	16, 34, 39, 42, 48
(ii) = HMIB, MeCN or CH_2Cl_2	OMs	alkyl, aryl, cyclobutyl 2-thienyl,	H, Me, Ph, COPh, COMe, $CO_2C_2H_5$	$-(CH_2)_4-$, 	32, 33, 35
(iii) = HCIB, MeCN or CH_2Cl_2		alkyl, aryl,	H, Me	$-(CH_2)_4-$	36

Scheme 5

3.2 α-Functionalized ketones via α-tosyloxyketones

Recent work[34,38-43] and previous studies[44,45] have established that α-halogenoketones (HK) and α-tosyloxyketones (TK) mostly behave analogously. For example, the most common property of both HK and TK is to undergo nucleophilic substitution to give various α-substituted ketones. This is an important observation because the TK-mediated approach can offer a better and safer alternative to a large number of organic syntheses involving highly lachrymatory and toxic HK in their conventional approach. The further advantage of the I^{III} based TK mediated approach is that it is generally not necessary to isolate TK, and the ketones are directly transformed into products. It is also noteworthy that the α-functionalized ketones thus obtained are precursors for a wide variety of heterocyclic compounds.

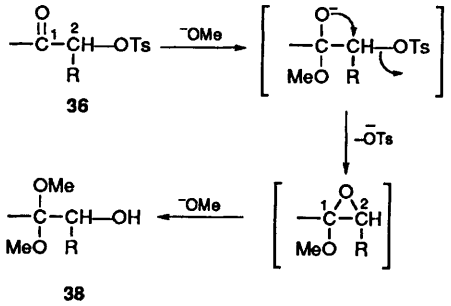
The results of these investigations have provided a large variety of α-functionalized ketones and some of these are summarized in tabular form in **Scheme 8**. It should be noted that the formation of **37** [X = OH, condition (ix)] from **36** occurs via acid hydrolysis of the corresponding α-hydroxydimethylacetal **38**, and a reasonable pathway for the conversion of **36** into **38** is outlined in **Scheme 9**.[48]



35 **36** **37**

Conditions	X	Ref.
(i) = PPh_3	$^+PPh_3OTs^-$	46
(ii) = 		46
(iii) = Me_2S	$^+SMe_2OTs^-$	46
(iv) = KSCN	SCN	43
(v) = $ArNH_2$	NHAr	42
(vi) = $NaNO_2$, H_2O	OH	47
(vii) = $ArCO_2H$–Et_3N	OCOAr	34
(viii) = ArOH–anh.K_2CO_3/EtOH	OAr	34
(ix) = (a) KOH–MeOH, 0–5 °C (b) H_3O^+	OH	48

Scheme 8



36 **38**

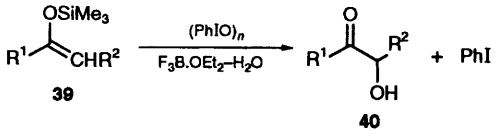
Scheme 9

4 α-Functionalizations of carbonyl compounds from the oxidations of silyl enol ethers

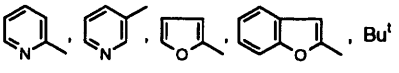
4.1 α-Hydroxylations

The results presented earlier indicate the wide applicability of IBD–KOH/MeOH to bring about α-hydroxylations of ketones and some α,β-unsaturated ketones. Nevertheless, the α-hydroxylation route suffers from the following shortcomings: (i) hydrolysis of some acetals to ketones is problematic.[49-51] (ii) certain compounds which contain groups sensitive to strong basic conditions are affected during oxidation, thereby giving poor results. (iii) the method is limited to α-hydroxyketones.

To overcome the aforementioned limitations, Moriarty *et al.*[50] have developed an alternative I^{III} mediated route for the direct α-hydroxylation of ketones. Their original procedure involved the treatment of silyl enol ethers of acetophenones and acetylpyridines with iodosobenzene–boron-trifluoride-etherate–water in dichloromethane at −40°C.[50] However, these conditions were not successful when applied to the α-hydroxylations of aliphatic ketones, propiophenones, and several heterocyclic ketones. Improved experimental conditions developed later on used iodosobenzene in water as a solvent at 0–5°C[51] (**Scheme 10**). This was an extremely useful development because it not only solved the problem of α-hydroxylation of ketones but also formed the basis for superior alternatives to other existing methods for the α-functionalization of ketones. For example, one of the major advantages of this methodology is that α-hydroxylations of esters can also be effected using similar conditions[52] (**Scheme 11**). Perhaps the most significant aspect of the development, however, is the versatility of the approach in introducing several other functionalities at the α-positions of carbonyl compounds, and the following portions of this section are devoted to brief details of these results.



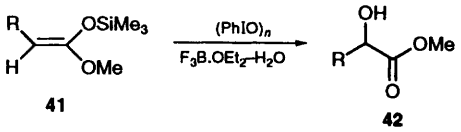
39 **40**

R^1 = aryl,  , Bu^t

R^2 = H, Me

R^1R^2 = —$(CH_2)_4$—

Scheme 10

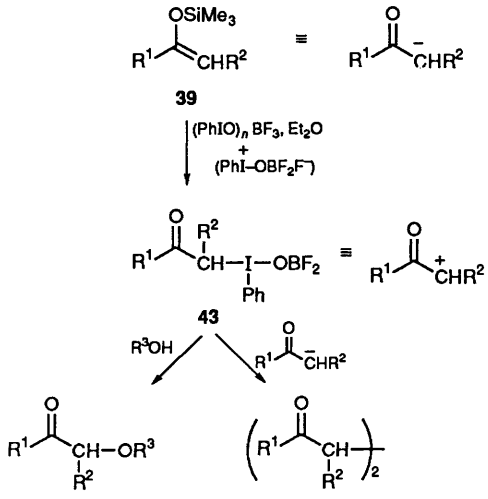


41 **42**

R = alkyl, aryl

Scheme 11

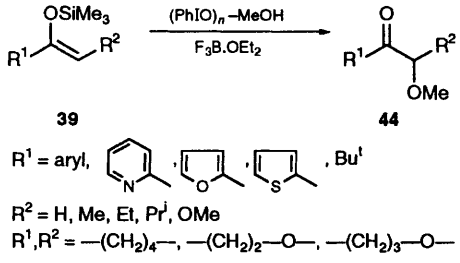
The mechanistic pathway for the reactions involving silyl enol ethers is given in **Scheme 12**. Thus **39** first leads to the intermediate **43**, the synthetic equivalent of a carbocation, and the reaction is completed by nucleophilic attack of water or some other nucleophile (**Scheme 12**).



Scheme 12

4.2 α-Alkoxylations

Ketones, esters, and lactones are smoothly converted into their corresponding α-alkoxylated carbonyl compounds, **44**[53,54] and various examples showing the generality of this methodology are outlined in **Scheme 13**.

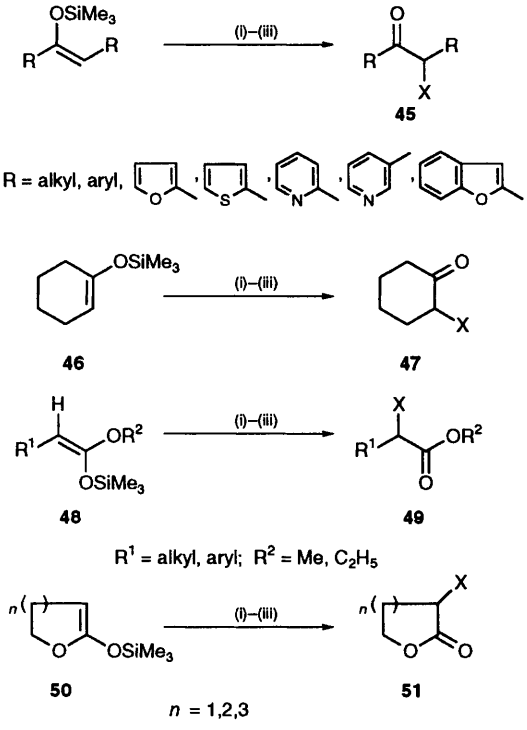


Scheme 13

An interesting point to note in the α-alkoxylations of ketones is that neither α-hydroxydimethylacetals (Section 2) nor rearranged products, 2-arylalkanoates (formed in the hypervalent iodine oxidation of alkyl aryl ketones in MeOH or trimethyl orthoformate)[55] are formed under these reaction conditions.

4.3 α-Acetoxylations, tosyloxylations, and mesyloxylations

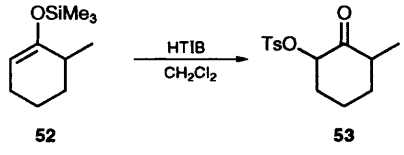
Silyl enol ethers of ketones have also been successfully converted into α-acetoxy- (**45**, X = OAc), tosyloxy- (**45**, X = OTs) and mesyloxy-ketones (**45**, X = OMs) by using IBD,[54,56] HTIB,[57] and HMIB,[57] respectively (**Scheme 14**). Although the methods of Mizukami *et al.*[14] and Koser *et al.*[16] provide a direct approach for α-functionalizations of ketones, the major drawback of their approaches is that these reactions proceed with



Condition	X	Ref.
(i) IBD–$F_3B.OEt_2$	OAc	54, 56
(ii) HTIB, CH_2Cl_2, r.t.	OTs	57
(iii) HMIB, CH_2Cl_2, r.t.	OMs	57

Scheme 14

relatively low regioselectivity. However, sulfonyloxylations involving silyl enol ethers are regioselective. For example, 2-methyl-6-tosyloxycyclohexanone **53** can be prepared regioselectively from 1-trimethylsilyloxy-6-methylcyclohex-1-ene **52** with HTIB in dichloromethane[57] (**Scheme 15**).



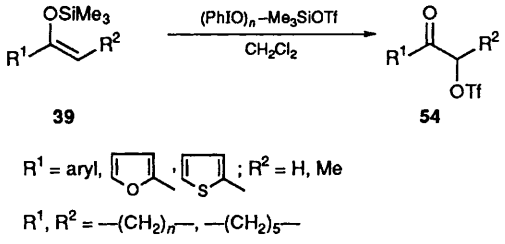
Scheme 15

Furthermore, another advantage of this approach is that it permits the preparation of α-sulfonyloxyketones **45** which contain acid sensitive or oxidizable ring systems, such as furan and pyridine[57] (α-sulfonyloxylated products are not accessible by the original Koser approach).

This approach has also been found to be suitable for the α-functionalizations of esters **48** → **49** and lactones **50** → **51**, as shown in **Scheme 14**.[54,57]

4.4 α-Trifloxylations

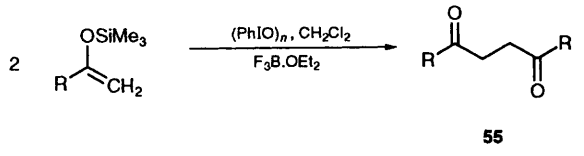
The treatment of silyl enol ethers with iodosobenzene in the presence of trimethylsilyl triflate in dichloromethane has been shown to afford good yields of α-(trifluoromethanesulfonyloxy)ketones (**54**, **Scheme 16**).[58] It seems likely that the active reagent in these reactions is [trimethylsilyloxy(trifluoromethanesulfonyloxy)iodo] benzene.



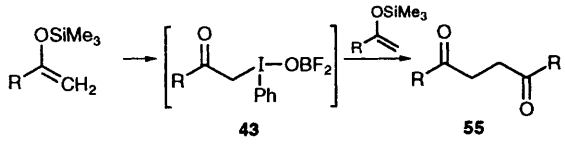
Scheme 16

4.5 1,4-Diketones by carbon–carbon bond formation

Hypervalent iodine oxidations of silyl enol ethers of ketones with iodosobenzene/boron trifluoride etherate in dichloromethane, in the absence of any external nucleophile result in carbon–carbon coupling reactions leading to the formation of the corresponding butane-1,4-diones.[59,60] (**55, Scheme 17**). The 1,4-diones, of course, are important intermediates in the synthesis of pyrroles, furans, and thiophenes (**Scheme 17**). However, the synthesis of unsymmetrical 1,4-diones by this method has not been so successful under the same reaction conditions. The reaction pathway is analogous to **Scheme 12**. In this case one equivalent of silyl enol ether gives the α-ketocarbonium ion equivalent **43**, which then couples with another equivalent of silyl enol ether (acting as nucleophile) to give the product (**Scheme 18**).



Scheme 17



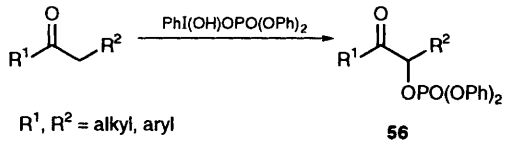
Scheme 18

Following earlier reports, joint efforts from Russian and American research groups[61] have solved the problem of the synthesis of unsymmetrical carbon–carbon coupled products by the *in situ* generation of the highly reactive iodonium salt [Ph-I$^+$-CH_2-COPh]BF_4^- and making use of (Ph-IO)$_n$-HBF_4 at −78°C.

5 Miscellaneous examples of α-functionalizations of carbonyl compounds

5.1 α-Phosphoryloxylations

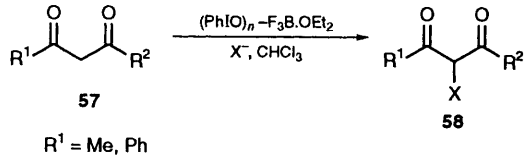
Koser *et al.*[62] have reported that α-phosphoryloxylations of ketones can be achieved using [hydroxy(bis(phenyloxy)phosphory)oxoiodo] benzene in acetonitrile (**Scheme 19**). The reaction proceeds through a pathway similar to α-sulfonyloxylation, where in this case the nucleophile is $^-$O-P(OPh)$_2$O.



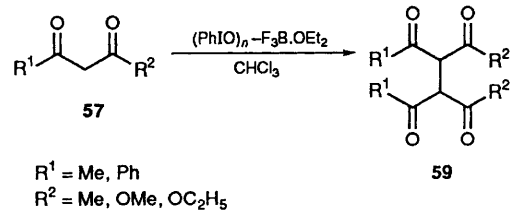
Scheme 19

5.2 α-Functionalizations of β-dicarbonyl compounds using iodosobenzene

Iodosobenzene, which is polymeric in nature, has been employed successfully to effect one-pot α-functionalizations of various β-dicarbonyl compounds. For example, treatment of the β-dicarbonyl compounds **57** with iodosobenzene and azidotrimethylsilane in chloroform under reflux gives α-azido-β-dicarbonyl compounds[34] **58**, X = N_3. Similarly, use of methanesulfonic acid and alcohol in place of azidotrimethylsilane has provided α-mesyloxy- and α-alkoxy-β-dicarbonyl compounds, respectively[34] (**Scheme 20**). When two equivalents of the β-dicarbonyl compounds **57** are treated with 1.2 equivalents of (Ph-IO)$_n$-$F_3B.OEt_2$ (1.3 equivalents) in chloroform, self-coupling at the α-position occurs[34] leading to the dimers **59** (**Scheme 21**).

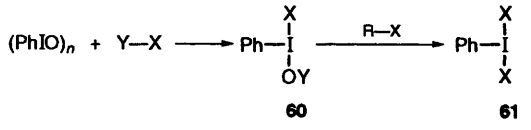


Scheme 20



Scheme 21

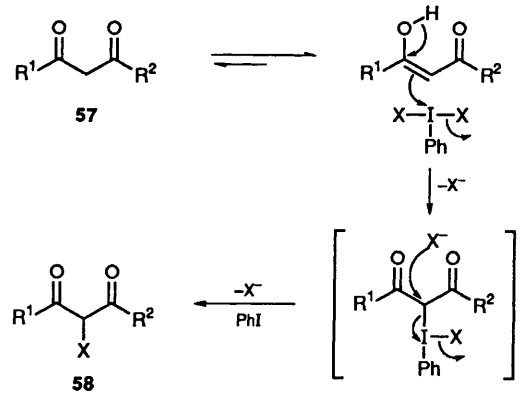
In all these transformations, iodosobenzene and the nucleophile afford hypervalent iodine reagents (**60** or **61**) as outlined in **Scheme 22**. A mechanism for the formation of **58** is given in **Scheme 23**, and the mechanism of the self-coupling leading to **59** is analogous to that shown in the synthesis of 1,4-diketones **55**.



60 **61**

Y = H, $SiMe_3$; X = N_3, OSO_2Me, OMe

Scheme 22



Scheme 23

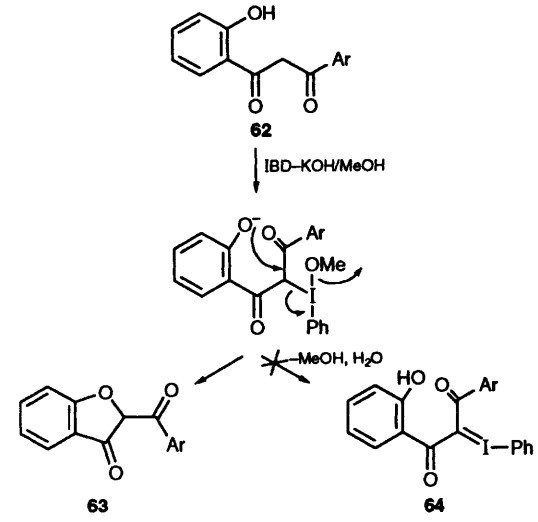
5.3 Synthesis of oxygen-containing heterocycles by intramolecular participation

An important application of the methodologies shown above lies in the formation of oxygen-containing heterocyclic compounds when intramolecular participation by a suitably placed oxygen-containing functional group occurs. These results are presented in the following subsections (5.3.1–5.3.3) according to the type of reagent used.

5.3.1 Using IBD–KOH/MeOH

5.3.1.1 2-Aroylcoumaran-3-ones

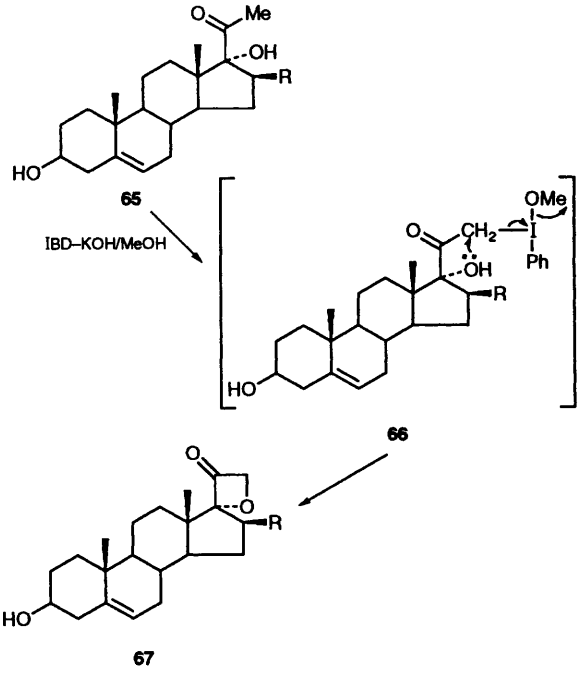
The synthesis of coumaran-3-ones involving the intramolecular participation of an *o*-hydroxyl group has been described in a previous review.[6] In a continuation of these studies, it has been found that the oxidation of α-aroyl-*o*-hydroxyacetophenones (**62**, β-diketones) using IBD–KOH/MeOH provides a useful route for obtaining 2-aroylcoumaran-3-ones[63] **63**. A noticeable feature of this reaction is that the β-diketones **62** do not give ylides **64**, a fact well established in the literature[64] for other β-dicarbonyl compounds (**Scheme 24**).



Scheme 24

5.3.1.2 Steroidal spiro-oxetan-3-ones

Taruta *et al.*[65] have shown that 17β-acetyl-17α-hydroxysteroids **65** on oxidation with IBD–KOH/MeOH at 20°C give the novel steroidal spiro-oxetan-3-ones **67**. This is an interesting example of intramolecular participation where the C-17α-hydroxyl group is an intramolecular nucleophile (**66** → **67**), as compared to $^-$OMe which acts as an intermolecular nucleophile (**Scheme 25**).



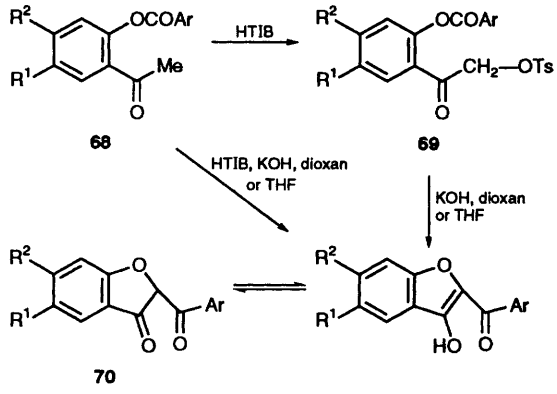
Scheme 25

5.3.2 Using HTIB, MeCN, or CH_2Cl_2

5.3.2.1 2-Aroylcoumaran-3-ones

The oxidations of *o*-aroyloxyacetophenones **68** with HTIB, followed by Baker–Venkataraman rearrangement of the resulting

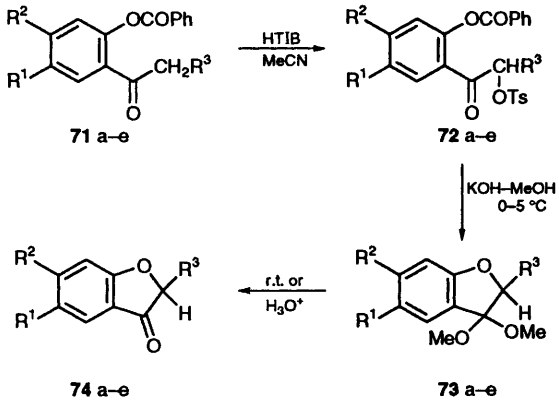
o-aroyloxy-α-tosyloxyacetophenones **69** with potassium hydroxide in dioxan or THF at reflux temperature leads to the formation of 2-aroylcoumaran-3-ones **70** (**Scheme 26**).[66]



Scheme 26

5.3.2.2 Coumaran-3-ones via their dimethylacetals

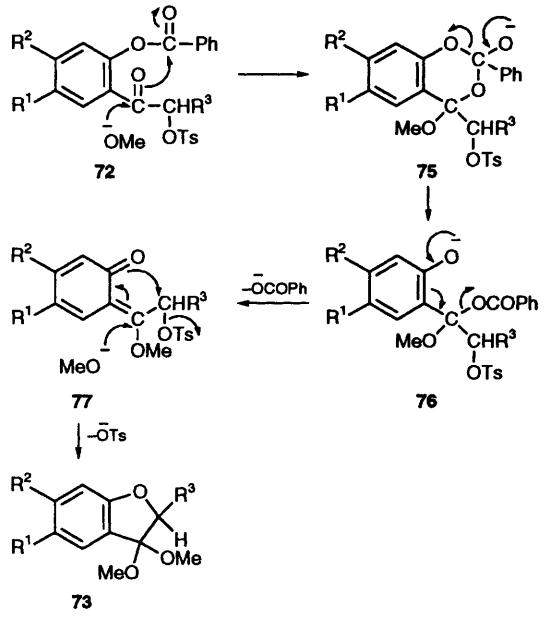
Treatment of 2-(α-tosyloxy)acyl phenyl benzoate **72**, obtained from *o*-benzoyloxyacetopropiophenones **71** using HTIB, with methanolic potassium hydroxide at 0–5°C leads to the formation of coumaran-3-one dimethylacetals **73** by way of intramolecular cyclization. These dimethylacetals **73** then undergo hydrolysis to the corresponding coumaran-3-ones **74** either by treatment with dilute HCl or by keeping them at room temperature for a few days (**Scheme 27**).[67] It is interesting to note that normal α-tosyloxyketones on similar treatment with KOH/MeOH give α-hydroxydimethylacetals of type **38** (**Scheme 9**).[48]



71–74	R¹	R²	R³
a	H	H	H
b	Me	H	H
c	Cl	H	H
d	Cl	Me	H
e	H	H	Me

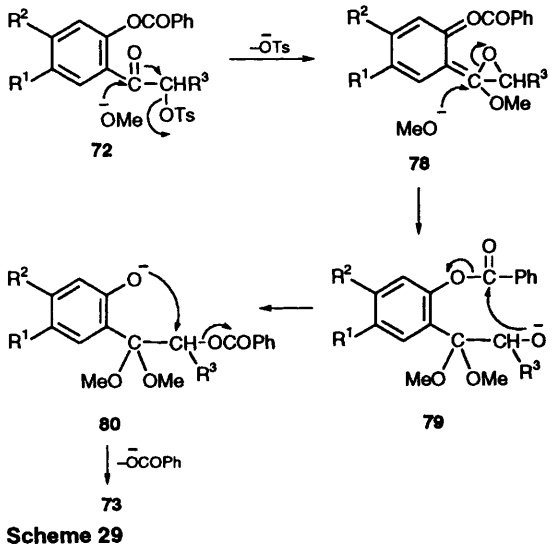
Scheme 27

Two alternative pathways which can be proposed to explain the transformation **72** → **73** are outlined in **Schemes 28** and **29**. According to the first pathway (**Scheme 28**), the reaction starts with attack of methoxide onto the ketonic group, which simultaneously attacks the carbonyl group associated with the ester, leading to the intermediate **76**. Loss of the benzoyloxy group from **76**, followed by addition of methoxide and cyclization then leads to the product, *viz.* **76** → **77** → **73**.



Scheme 28

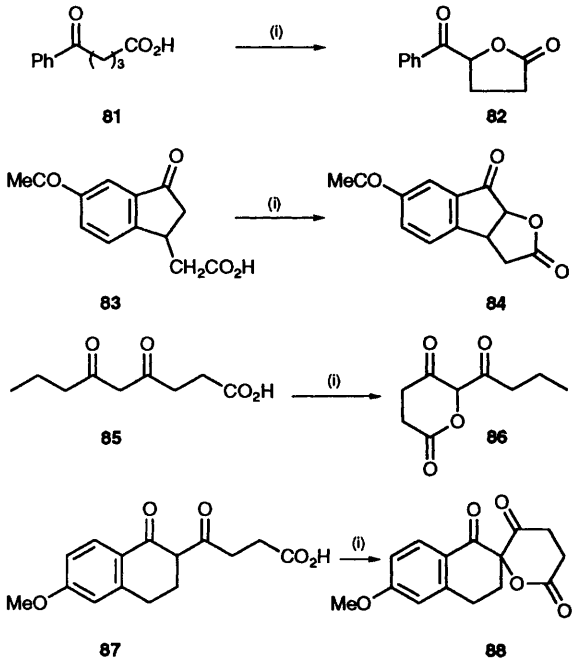
Alternatively, the reaction may proceed via the α-hydroxydimethylacetal **79**, formed according to **Scheme 29**, [**72** → **78** → **79**] which leads to a second intermediate **80** by nucleophilic attack of alkoxide or alcohol onto the carbonyl function of the benzoyloxy group. Finally, the cyclic product **73** is obtained by intramolecular participation of phenoxide ion accompanied by displacement of the benzoyloxy group.



Scheme 29

5.3.2.3 Oxolactones

When the 5-oxocarboxylic acids **81** and **83**, and the 4,6-dioxo-carboxylic acids **85** and **87** are treated separately with HTIB in dichloromethane, intramolecular participations by the carboxyl groups take place leading to the formation of the corresponding oxolactones **82** and **84**, and dioxo-δ-lactones **86** and **88**, respectively[68] (**Scheme 30**).

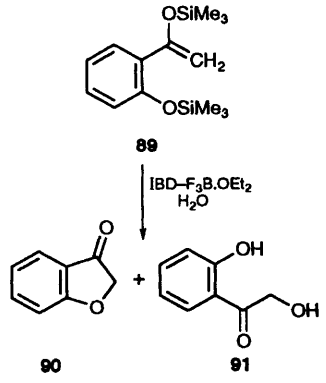


Scheme 30

5.3.3 Using $(PhIO)_n$-$F_3B.OEt_2$, H_2O

5.3.3.1 Coumaran-3-ones

The oxidation of 1-trimethylsilyloxy-1-(2-trimethylsilyloxyphenyl) ethane **89** with $(PhIO)_nF_3B.OEt_2$, H_2O results in the formation of coumaran-3-one **90** as the major product, by a route involving intramolecular participation of the *o*-hydroxyl group, in addition to minor amounts of the expected α-hydroxylated product **91**[69] (**Scheme 31**).



Scheme 31

6 Conclusions

It is evident from the foregoing discussion that the applications of organo I^{III} reagents have offered a large number of simple alternatives to existing methods to bring about α-functionalizations of carbonyl compounds. The hypervalent iodine approach mostly involves one-step direct procedures, with simple experimentation, and generally gives good yields of products. Another attractive feature of hypervalent-iodine mediated synthesis is their non-toxic nature as compared to methods involving $Hg^{(II)}$, $Tl^{(III)}$, and $Pb^{(IV)}$ reagents.

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