Use of 1,3-Dioxin-4-ones and Related Compounds in Synthesis. Part 37.[1] 5-Trifluoromethyl-1,3-dioxin-4-ones as Versatile Building Blocks for Trifluoromethylated Aliphatic Compounds[2]

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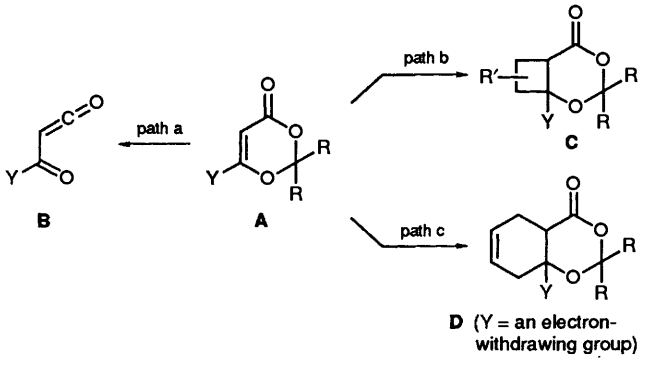
Synthesis of 5-trifluoromethyl-1,3-dioxin-4-ones and their use for the preparation of a variety of trifluoromethylated aliphatic compounds are described. Their usefulness has been demonstrated either by the formation of α-trifluoromethyl-β-keto esters *via* the corresponding acylketenes or by their direct participation in pericyclic reactions as a $_{\pi}2$ component.

Owing to the ready manipulations depicted in Scheme 1, utilization of 1,3-dioxin-4-ones for the synthesis of a variety of organic molecules has been well documented (Scheme 1).[3]



Scheme 1 *Reagents and conditions:* path a, heat or *hv* (254 nm); path b, R′CH=CH_2, *hv* (≥300 nm); path c, CH_2=CHCH=CH_2, heat

Since the attachment of a trifluoromethyl group to an sp^3 carbon is generally a more formidable task than is the bonding of a trifluoromethyl group to an sp^2 carbon,[4] we thought that dioxinones having a trifluoromethyl group at the 5-position could serve as versatile building blocks for trifluoromethylated aliphatic compounds. This idea was very attractive because not only have 5-halogenated dioxinones been synthesized previously by us by reaction of 5-unsubstituted dioxinones with the corresponding *N*-halogenated succinimide followed by treatment with an appropriate base,[5] but also an iodine atom attached to a C=C double bond could readily be replaced with a trifluoromethyl group.† In this paper, we report the synthesis of 5-trifluoromethylated dioxinones and their conversion into α-trifluoromethylated keto esters *via* the corresponding trifluoromethylated acylketenes.[7] This paper also includes some preliminary results from their successful use as components in [2 + 2]photocycloadditions (as the enones) and in Diels–Alder reactions (as the dienophiles).

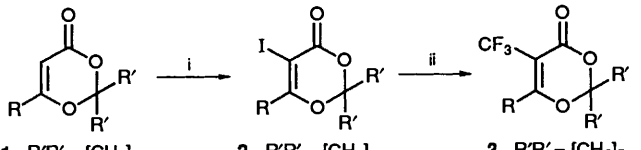
Results and Discussion

Synthesis of 5-Trifluoromethyl-1,3-dioxin-4-ones.—When the 5-iodo-1,3-dioxin-4-ones **2a–c** and **2′a–c**,[5] prepared from the corresponding 5-unsubstituted derivatives **1a–c** and **1′a–c**, were allowed to react with trifluoromethylcopper in hexamethylphosphoric triamide (HMPA),[6] the corresponding trifluoromethylated derivatives **3a–c** and **3′a–c** were obtained in satisfactory yield (Scheme 2; Table 1).

Table 1 5-Trifluoromethyldioxinones prepared

Precursor	R	R′R′	Yield of 2 or 2′ (%)	Yield of 3 or 3′ (%)
1a	H	$[CH_2]_5$	80	89
1b	Me	$[CH_2]_5$	83	54[a]
1c	Ph	$[CH_2]_5$	72	62
1′a	H	Me, Me	75	64
1′b	Me	Me, Me	60	71
1′c	Ph	Me, Me	55	95

[a] The pentafluoroethyl derivative was also obtained, in 23% yield.



Scheme 2 *Reagents and conditions:* i, *N*-iodosuccinimide (NIS), AcOH; ii, $CuCF_3$, hexamethylphosphoric triamide (HMPA), 50–60 °C

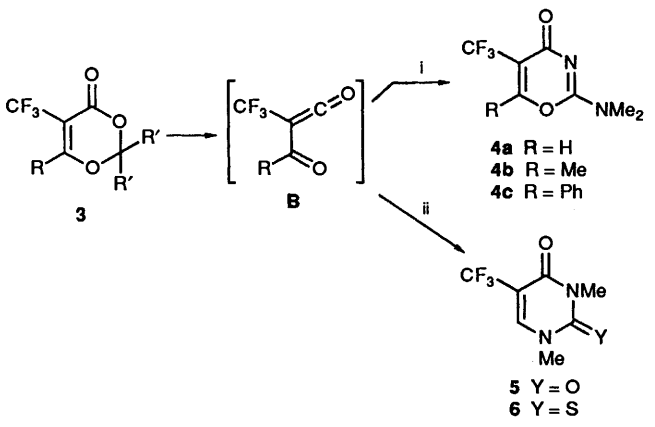
In some cases, small amounts of the pentafluoroethyl derivatives [*e.g.*, **3b** (C_2F_5 instead of CF_3)] were obtained concomitantly. It is obvious that these compounds were formed by coupling of the pentafluoroethyl complex generated from the trifluoromethyl complex.‡

Preparation of α-Trifluoromethylated Acyl Esters.—In order to verify that the trifluoromethylated dioxinones **3** could open to the corresponding acylketenes just like the other, untrifluorinated dioxinones,[3] compounds **3** were treated with dimethylcyanamide in an appropriate inert solvent at reflux. The expected oxazinones **4** were obtained in satisfactory yield. Reaction of dioxinone **3a** with 1,3-dimethylurea or its thio derivative under the same conditions gave the uracil **5** and the thiouracil **6** having a trifluoromethyl group at the 5-position (Scheme 3). The results are summarized in Table 2.

The above finding then led us to use these trifluoromethylated dioxinones as the direct precursors of α-trifluoromethyl-

† The most useful trifluoromethylation reaction employs a trifluoromethyl-copper or -zinc complex and has wide applicability for aryl halides and related compounds.[6]

‡ The disproportionation of $[CF_3Cu]$ to $[CF_3CF_2Cu]$ was demonstrated either by spectroscopy or by the formation of pentafluoroethylated products in the trifluoromethylation reactions using trifluoromethylcopper complexes.[8]

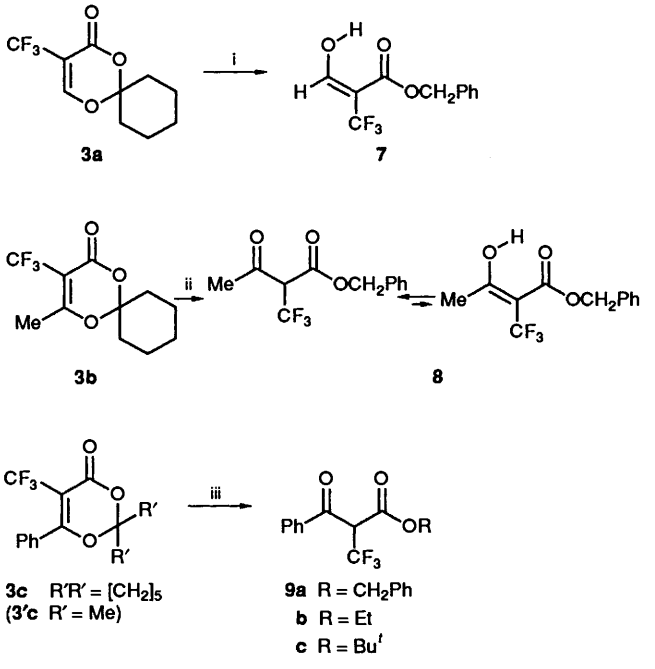


Scheme 3 *Reagents and conditions:* i, dimethylcyanamide, benzene, toluene or xylene, reflux; ii, 1,3-dimethylurea or 1,3-dimethylthiourea, toluene, reflux

Table 2 5-Trifluoromethyl-oxazines and -uracils prepared

Precursor	Solvent	Time (*t*/min)	Product	Yield (%)
3a	toluene	20	**4a**	91
3b	xylene	40	**4b**	81
3c	xylene	40	**4c**	93
3'a	benzene	60	**4a**	79
3'b	toluene	40	**4b**	79
3'c	toluene	40	**4c**	85
3a	toluene	150[a]	**5**	84
3a	toluene	90[a]	**6**	58

[a] The toluene solution of compound **3a** was added dropwise into the refluxing toluene solution of urea.



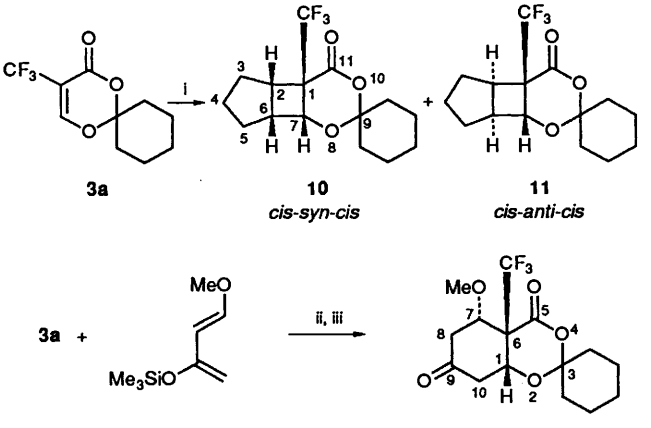
Scheme 4 *Reagents and conditions:* i, $PhCH_2OH$, toluene, reflux; ii, $PhCH_2OH$, xylene, reflux; iii, ROH, xylene (toluene), reflux

ated β-keto esters. The synthesis of these esters is particularly difficult, because, under basic conditions, they are readily dehydrofluorinated to give β,β-difluoroacrylic acid intermediates which are prone to hydrolysis and decarboxylation.[9] Though several methods are available for the synthesis of these esters,[4,10,11] there is a clear need for a new and general method.

According to the general procedure for the conversion of the dioxinones into β-keto esters *via* the corresponding acylketenes,[12] compound **3'c** was refluxed in toluene containing Bu^{t}OH to give the ester **9c** in nearly quantitative yield. This reaction proceeded irrespective of either the 6-substituted dioxinone **3a–c** or the alcohol (*e.g.*, benzyl alcohol) used, to give the corresponding β-keto esters **7–9c** (Scheme 4). The results are summarized in Table 3.

A brief comment concerning the keto–enol tautomerism of the trifluoromethylated β-keto esters seems to be worth recording. By the analysis of ^{1}H NMR spectra measured in $CDCl_3$, it is obvious that, except for the acetoacetates **8** which exist in an equilibrium between two forms (keto:enol ~9:1), the formyl esters **7** exist solely as the enol form whereas the benzoyl acetates **9** are in the keto form.

Preliminary Use of 5-Trifluoromethyl-1,3-dioxin-4-ones in [2 + 2]Photocycloaddition and Diels–Alder Reactions.—In addition to their transformation *via* acylketene intermediates (see path a in Scheme 1), the dioxinones undergo [2 + 2]photocycloaddition (**A** ⟶ **C**)[13] and Diels–Alder reaction (**A** ⟶ **D**)[14] by using their C–C double bond as a $_\pi$2 component, and this provides further examples of the use of these dioxinones as alternatives for the enol form of masked acylacetic acids[3] (see paths b and c in Scheme 1). Our preliminary results from the use of the 5-trifluoromethyldioxinone **3a** in these pericyclic reactions shown in Scheme 5 show clearly that these dioxinones



Scheme 5 *Reagents and conditions:* i, cyclopentene, AcOEt, *hv* (254 nm) (yield 68%, **10**:**11** ~2:1); ii, toluene, 10 kbar, room temperature; iii, KF, THF (82% overall yield from **3a**)

could participate in these two reactions. Thus, in the first instance, photoaddition of the dioxinone **3a** to cyclopentene afforded the expected adduct in 68% yield as a mixture of *cis-syn-cis* **10** and *cis-anti-cis* isomers **11**. Two isomers could be separated by medium-performance liquid chromatography (MPLC: Lobar column) to give a less polar (**10**) and a more polar adduct (**11**) in ~2:1 ratio. By analysis of the 500 MHz ^{1}H NMR spectra, the major adduct **10** was assigned the *cis-syn-cis* configuration [7-H (δ 4.70) as dd (*J* 7.5 and 1.5 Hz: the latter was obviously due to a long-range coupling between 7-H and 2-H: *cis*-relationship in a W-conformation of the cyclobutane ring[15])], while the 7-H signal of isomer **11** appeared at δ 4.47 as a doublet (*J* 3.0 Hz) without any such coupling. In the second instance, compound **3a** reacted with 1-methoxy-3-(trimethylsiloxy)buta-1,3-diene (Danishefsky's diene) to give the single adduct **12**. Owing to a long-range coupling (2 Hz) between 1-H and 7-H in the ^{1}H NMR spectrum of adduct **12**, it was reasonable to assume that the reaction had proceeded *via* the *endo* transition state. Though this reaction proceeded only

Table 3 α-Trifluoromethyl-β-keto esters prepared

Precursor	Alcohol	Solvent	Time (*t*/min)	Product	Yield (%)	Keto:enol
3a	$PhCH_2OH$	toluene	30	**7**	85	0:100
3b	$PhCH_2OH$	xylene	20	**8**	quant.	90:10
3c	$PhCH_2OH$	xylene	20	**9a**	quant.	100:0
3c	EtOH	xylene	40	**9b**	85	100:0
3'c	Bu^tOH	toluene	20	**9c**	quant.	100:0

under high-pressure conditions (10 kbar;* room temperature), the same reaction using the unsubstituted dioxinone **1a** did not proceed at all. This fact indicated that attachment of a trifluoromethyl group at the 5-position of the dioxinone ring enhanced the reactivity of the dioxinone **1a** as the dienophile. The result seems to indicate not only the usefulness of the dioxinone as a $_{\pi}2$ component in these two pericyclic reactions but also that these dioxinones offer flexible methods for the preparation of a variety of trifluoromethylated compounds.

In conclusion, the approaches described in this paper suggest that the use of 5-trifluoromethyldioxinones **3** makes it possible to synthesize many compounds (both aliphatic and aromatic) having a trifluoromethyl group. Since the homochiral dioxinones having a chiral auxiliary at the acetal position are readily attained,[3,13,14] the use of such chiral dioxinones having a trifluoromethyl group at the 5-position for pericyclic reactions (Diels–Alder reaction and [2 + 2]photocycloaddition) would serve as suitable precursers for EPC (enantiomerically pure compound) synthesis of trifluoromethylated aliphatic compounds. We are currently investigating this area, as well as that with 5-fluorodioxinone[16] as substrate.

Experimental

M.p.s were determined on a Yanagimoto micromelting point apparatus (MP-S2), and are uncorrected. IR spectra were recorded on a JASCO A-102 spectrometer. ^1H NMR spectra were recorded with tetramethylsilane as internal standard on a JEOL JNM PMX-6OSI or a JNM-FX500 spectrometer at 60 MHz or 500 MHz, respectively. *J*-Values are given in Hz. High-resolution mass spectra were recorded on a JEOL JMS-01SG-2-system. Wakogel (C-200) was employed for silica gel column chromatography. Merck Kieselgel 60F 254 was employed for TLC. MPLC was performed with a Merck Lobar column (LiChroprep Si 60). The irradiation source used for photoreactions was a Rayonet photochemical reactor lamp (Cat. No. RPR-2537 Å) and the reactions were carried out in a quartz vessel. Substrate dioxin-4-ones **1a–c**,[1] **1'a–c**,[1] **2a**[5] and **2'a**[5] were prepared according to the literature procedure.

General Procedure for the Preparation of 5-*Iododioxinones* (**2** *and* **2'**).—5-*Iodo*-6-*methyl*-4-*oxo*-4H-1,3-*dioxine*-2-*spirocyclohexane* **2b**. A solution of 6-methyl-4-oxo-4*H*-1,3-dioxine-2-spirocyclohexane **1b** (0.91 g, 5.0 mmol) and *N*-iodosuccinimide (NIS) (1.66 g, 7.5 mmol) in acetic acid (12 cm^3) was stirred for 15 h at room temperature in the dark. The reaction mixture was diluted with water and extracted with CH_2Cl_2. The organic layer was washed with water and dried over $MgSO_4$. The residue obtained after evaporation of the solvent was chromatographed on silica gel [hexane–AcOEt (10:1)] to give *title compound* **2b** as pale yellow prisms (1.28 g, 83%); m.p. 78.5–79.5 °C (from hexane) (Found: C, 38.9; H, 4.3. $C_{10}H_{13}IO_3$ requires C, 39.0; H, 4.25%); $\nu_{max}(CHCl_3)/cm^{-1}$ 2960, 1725, 1605 and 1325; $\delta_H(CDCl_3)$ 1.2–2.2 (10 H, m, CH_2 × 5) and 2.30 (3 H, s, Me).

The following compounds were prepared in a similar manner: 5-*Iodo*-4-*oxo*-6-*phenyl*-4H-1,3-*dioxine*-2-*spirocyclohexane* **2c**. Obtained as prisms (72%); m.p. 153–154.5 °C (from AcOEt–hexane) (Found: C, 48.7; H, 4.2. $C_{15}H_{15}IO_3$ requires C, 48.65; H, 4.1%); $\nu_{max}(CHCl_3)/cm^{-1}$ 2960, 1720 and 1330; $\delta_H(CDCl_3)$ 1.2–2.3 (10 H, m, CH_2 × 5) and 7.2–7.9 (5 H, m, Ph).

5-*Iodo*-2,2,6-*trimethyl*-1,3-*dioxin*-4-*one* **2'b**. Obtained as prisms (60%); m.p. 62–62.5 °C (from Et_2O–hexane) (Found: M^+, 267.959. $C_7H_9IO_3$ requires M, 267.960); $\nu_{max}(CHCl_3)/cm^{-1}$ 1730 and 1600; $\delta_H(CDCl_3)$ 1.68 (6 H, s, Me × 2) and 2.30 (3 H, s, 6-Me).

5-*Iodo*-2,2-*dimethyl*-6-*phenyl*-1,3-*dioxin*-4-*one* **2'c**. Obtained as plates (55%); m.p. 121–122 °C (from AcOEt–hexane) (Found: C, 43.7; H, 3.5. $C_{12}H_{11}IO_3$ requires C, 43.65; H, 3.35%); $\nu_{max}(CHCl_3)/cm^{-1}$ 1720, 1590, 1575, 1330 and 1265; $\delta_H(CDCl_3)$ 1.83 (6 H, s, Me × 2) and 7.2–7.8 (5 H, m, Ph).

General Procedure for the Preparation of 5-*Trifluoromethyldioxinones* (**3** *and* **3'**).—4-*Oxo*-5-*trifluoromethyl*-4H-1,3-*dioxine*-2-*spirocyclohexane* **3a**. A suspension of trifluoromethyl iodide (8.82 g, 45 mmol), copper powder (4.57 g, 72 mmol,) and HMPA (18 cm^3) was stirred at 120–125 °C in a sealed tube for 3 h under Ar. To the mixture was added compound **2a** (4.43 g, 15 mmol) and the resultant solution was stirred at 55 °C for 1 h. The reaction mixture was then cooled and poured into ice–water, and insoluble material was removed by filtration through Celite. After extraction of the filtrate with diethyl ether, the organic layer was washed with water and dried over $MgSO_4$. The residue obtained after evaporation of the solvent was chromatographed on silica gel [hexane–CH_2Cl_2 (1:1)] to give the *title compound* **3a** as needles (3.14 g, 89%); m.p. 77.5–78.0 °C (from Et_2O–hexane) (Found: C, 51.0; H, 4.75. $C_{10}H_{11}F_3O_3$ requires C, 50.85; H, 4.7%); $\nu_{max}(CHCl_3)/cm^{-1}$ 2960, 1760, 1625, 1400 and 1150; $\delta_H(CDCl_3)$ 1.3–2.3 (10 H, m, CH_2 × 5) and 7.7 (1 H, br s, 6-H).

The following compounds were prepared in a similar manner: 6-*Methyl*-4-*oxo*-5-*trifluoromethyl*-4H-1,3-*dioxine*-2-*spirocyclohexane* **3b**. Obtained as an oil (54%) (Found: M^+, 250.082. $C_{11}H_{13}F_3O_3$ requires M, 250.082); $\nu_{max}(CHCl_3)/cm^{-1}$ 2960, 1740, 1630, 1400, 1375 and 1140; $\delta_H(CDCl_3)$ 1.3–2.3 (10 H, m, CH_2 × 5) and 2.27 (3 H, q, *J* 2, Me).

In this case, the corresponding pentafluoroethyl derivative was obtained as the less polar product: 6-*methyl*-4-*oxo*-5-*pentafluoroethyl*-4H-1,3-*dioxine*-2-*spirocyclohexane* was obtained as needles (23%); m.p. 64–64.5 °C (from pentane) (Found: C, 48.05: H, 4.4. $C_{12}H_{13}F_5O_3$ requires C, 48.0; H, 4.35%); $\nu_{max}(CHCl_3)/cm^{-1}$ 2960, 1745 and 1610; $\delta_H(CDCl_3)$ 1.3–2.3 (10 H, m, CH_2 × 5) and 2.27 (3 H, t, *J* 2, Me).

4-*Oxo*-6-*phenyl*-5-*trifluoromethyl*-4H-1,3-*dioxine*-2-*spirocyclohexane* **3c**. Obtained as needles (62%); m.p. 160–161 °C (from AcOEt–hexane) (Found: C, 61.65; H, 4.9. $C_{16}H_{15}F_3O_3$ requires C, 61.55; H, 4.85%); $\nu_{max}(CHCl_3)/cm^{-1}$ 2950, 1740, 1615 and 1390; $\delta_H(CDCl_3)$ 1.2–2.3 (10 H, m, CH_2 × 5) and 7.55 (5 H, s, Ph).

2,2-*Dimethyl*-5-*trifluoromethyl*-1,3-*dioxin*-4-*one* **3'a**. Ob-

* 1 bar = 10^5 Pa.

tained as an oil (64%) (Found: M^+, 196.034. $C_7H_7F_3O_3$ requires M, 196.035); $\nu_{max}(CHCl_3)/cm^{-1}$ 1760, 1645, 1495, 1345, 1295 and 1150; $\delta_H(CDCl_3)$ 1.77 (6 H, s, Me × 2) and 7.72 (1 H m, 6-H).

2,2,6-*Trimethyl*-5-*trifluoromethyl*-1,3-*dioxin*-4-*one* **3'b**. Obtained as an oil (71%) (Found: M^+, 210.054. $C_8H_9F_3O_3$ requires M, 210.050); $\nu_{max}(CHCl_3)/cm^{-1}$ 1750, 1630 and 1400; $\delta_H(CDCl_3)$ 1.73 (6 H, s, 2-Me × 2) and 2.27 (3 H, m, 6-Me).

2,2-*Dimethyl*-6-*phenyl*-5-*trifluoromethyl*-1,3-*dioxin*-4-*one* **3'c**. Obtained as needles (95%); m.p. 111.5–112.5 °C (from AcOEt–hexane) (Found: C, 57.35; H, 4.1. $C_{13}H_{11}F_3O_3$ requires C, 57.35; H, 4.05%); $\nu_{max}(CHCl_3)/cm^{-1}$ 1740, 1615, 1385 and 1375; $\delta_H(CDCl_3)$ 1.87 (6 H, s, Me × 2) and 7.60 (5 H, s, Ph).

General Procedure for the Preparation of 5-*Trifluoromethyloxazines* **4**.—2-*Dimethylamino*-5-*trifluoromethyl*-1,3-*oxazin*-4-*one* **4a** *from compound* **3a**. A solution of compound **3a** (47.2 mg, 0.2 mmol) and dimethylcyanamide (28.0 mg, 0.4 mmol) in toluene (2 cm^3) was refluxed for 20 min. The residue obtained after evaporation of the solvent was chromatographed on silica gel [AcOEt–EtOH (4:1)] to give the *title compound* **4a** as needles (38 mg, 91%); m.p. 113–114 °C (from AcOEt–hexane) (Found: C, 40.35; H, 3.4; N, 13.5. $C_7H_7F_3N_2O_2$ requires C, 40.4; H, 3.4; N, 13.45%); $\nu_{max}(CHCl_3)/cm^{-1}$ 1685, 1600, 1590 and 1330; $\delta_H(CDCl_3)$ 3.17 (6 H, s, Me × 2) and 7.80 (1 H, m, 6-H).

The title compound **4a** was also obtained, in 79% yield, when compound **3'a** was the starting material.

The following compounds were prepared in a similar manner:

2-*Dimethylamino*-6-*methyl*-5-*trifluoromethyl*-1,3-*oxazin*-4-*one* **4b**. Obtained as plates (81% yield from **3b** and 79% yield from **3'b**); m.p. 90.0–91.5 °C (from AcOEt–hexane) (Found: C, 43.2; H, 4.1; N, 12.65. $C_8H_9F_3N_2O_2$ requires C, 43.25; H, 4.1; N, 12.6%); $\nu_{max}(CHCl_3)/cm^{-1}$ 1680, 1600, 1590 and 1365; $\delta_H(CDCl_3)$ 2.40 (3 H, q, *J* 2, 6-Me) and 3.17 (6 H, s, Me × 2).

2-*Dimethylamino*-6-*phenyl*-5-*trifluoromethyl*-1,3-*oxazin*-4-*one* **4c**. Obtained as needles (93% yield from **3c** and 85% yield from **3'c**); m.p. 185–186 °C (from AcOEt–hexane) (Found: C, 55.15; H, 4.0; N, 9.75. $C_{13}H_{11}F_3N_2O_2$ requires C, 54.95; H, 3.9; N, 9.85%); $\nu_{max}(CHCl_3)/cm^{-1}$ 1665, 1605, 1590 and 1360; $\delta_H(CDCl_3)$ 3.16 (3 H, s, NMe), 3.22 (3 H, s, NMe) and 7.55 (5 H, s, Ph).

General Procedure for the Preparation of Uracils.—1,3-*Dimethyl*-5-*trifluoromethyluracil* **5**.[17] A solution of compound **3a** (47.2 mg, 0.2 mmol) in toluene (2 cm^3) was added dropwise during 2 h into a solution of 1,3-dimethylurea (35.2 mg, 0.4 mmol) in toluene (2 cm^3) under reflux. After additional reflux for 30 min, the solvent was evaporated off under reduced pressure. The residue was purified by silica gel column chromatography [hexane–AcOEt (1:1)] to give the *title compound* **5** as plates (35 mg, 84%); m.p. 108–109 °C (from AcOEt–Et_2O) (Found: C, 40.55; H, 3.55; N, 13.45. $C_7H_7F_3N_2O_2$ requires C, 40.4; H, 3.4; N, 13.45%); $\nu_{max}(CHCl_3)/cm^{-1}$ 1725, 1690 and 1680; $\delta_H(CDCl_3)$ 3.37 (3 H, s, Me), 3.50 (3 H, s, Me) and 7.70 (1 H, m, 6-H).

1,3-*Dimethyl*-5-*trifluoromethyl*-2-*thiouracil* **6**. This was obtained in the same manner by using 1,3-dimethylthiourea instead of 1,3-dimethylurea, as needles (58%); m.p. 115–116.5 °C (from AcOEt–hexane) (Found: C, 37.6; H, 3.2; N, 12.35. $C_7H_7F_3N_2OS$ requires C, 37.75; H, 3.15; N, 12.3%); $\nu_{max}(CHCl_3)/cm^{-1}$ 1705, 1660, 1485 and 1150; $\delta_H(CDCl_3)$ 3.75 (3 H, s, Me), 3.83 (3 H, s, Me) and 7.91 (1 H, m, 6-H).

General Procedure for the Preparation of α-*Trifluoromethyl*-β-*keto Esters.*—(E)-*Benzyl* 3-*hydroxy*-2-*trifluoromethylacrylate* **7**. A solution of compound **3a** (47.2 mg, 0.2 mmol) and benzyl alcohol (22.7 mg, 0.21 mmol) in toluene (0.5 cm^3) was refluxed for 30 min. The solvent and cyclohexanone were evaporated off under reduced pressure to give the *title compound* **7** as an oil (42 mg, 85%) (Found: M^+, 246.051. $C_{11}H_9F_3O_3$ requires M, 246.050); $\nu_{max}(CHCl_3)/cm^{-1}$ 1680, 1420, 1190 and 1140; $\delta_H(CDCl_3)$ (enol form) 5.37 (2 H, s, CH_2Ph), 7.40 (5 H, s, Ph), 7.76 (1 H, br d, *J* 13, 3-H) and 12.35 (1 H, d, *J* 13, OH).

The following compounds were prepared in a similar manner:

Benzyl 3-*oxo*-2-*trifluoromethylbutyrate* **8**. Obtained as an oil (quant.) (Found: M^+, 260.065. $C_{12}H_{11}F_3O_3$ requires M, 260.066); $\nu_{max}(CHCl_3)/cm^{-1}$ 1760, 1735, 1260 and 1160; $\delta_H(CDCl_3)$ (keto:enol ~9:1) 2.30 (3 H, s, Me), 4.23 (1 H × 0.9, q, *J* 8, 2-H), 5.27 (2 H, s, CH_2Ph), 7.37 (5 H, s, Ph) and 14.00 (1 H × 0.1, s, OH).

Benzyl 3-*oxo*-3-*phenyl*-2-*trifluoromethylpropionate* **9a**. Obtained as an oil (quant.) (Found: M^+, 322.081. $C_{17}H_{13}F_3O_3$ requires M, 322.082); $\nu_{max}(CHCl_3)/cm^{-1}$ 1760, 1700, 1290, 1260, 1160 and 1110; $\delta_H(CDCl_3)$ (keto form) 5.13 (1 H, q, *J* 8, 2-H), 5.20 (2 H, s, CH_2), 7.20 (5 H, s, Ph) and 7.0–8.1 (5 H, m, Ph).

Ethyl 3-*oxo*-3-*phenyl*-2-*trifluoromethylpropionate* **9b**. Obtained as an oil (85%) (Found: M^+, 260.064. $C_{12}H_{11}F_3O_3$ requires M, 260.066); $\nu_{max}(CHCl_3)/cm^{-1}$ 1770, 1700, 1260, 1160 and 1110; $\delta_H(CDCl_3)$ (keto form) 1.23 (3 H, t, *J* 7, Me), 4.27 (2 H, q, *J* 7, CH_2), 5.17 (1 H, q, *J* 8, 2-H) and 7.3–8.2 (5 H, m, Ph).

tert-*Butyl* 3-*oxo*-3-*phenyl*-2-*trifluoromethylpropionate* **9c**. Obtained as needles (quant.); m.p. 53–54.5 °C (from hexane) (Found: C, 58.25; H, 5.4. $C_{14}H_{15}F_3O_3$ requires C, 58.35; H, 5.25%); $\nu_{max}(CHCl_3)/cm^{-1}$ 1750, 1700, 1255 and 1150; $\delta_H(CDCl_3)$ (keto form) 1.37 (9 H, s, Me × 3), 5.03 (1 H, q, *J* 8, 2-H) and 7.3–8.2 (5 H, m, Ph).

rel-(1R,2S,6R,7R)-11-*Oxo*-1-*trifluoromethyl*-8,10-*dioxatricyclo*[5.4.0.0^{2,6}]*undecane*-9-*spirocyclohexane* (cis-syn-cis) **10** *and* rel-(1R,2R,6S,7R)-11-*Oxo*-1-*trifluoromethyl*-8,10-*dioxaticyclo*-[5.4.0.0^{2,6}]*undecane*-9-*spirocyclohexane* (cis-anti-cis) **11**.—A solution of compound **3a** (71 mg, 0.3 mmol) and cyclopentene (390 mg, 6 mmol) in AcOEt (12 cm^3)–benzene (3 cm^3) was treated with bubbling argon for 5 min and then irradiated for 2 h. The residue obtained after evaporation of the solvent was chromatographed [hexane–AcOEt (20:1)] on silica gel to give the mixture of the two adducts (62 mg, 68%) (**10**:**11** ~2:1). Separation of this mixture by MPLC [hexane–Et_2O (100:1)] gave compound **10** (less polar; 38 mg, 42%) as an oil and compound **11** (more polar; 14 mg, 15%) as an oil.

For *compound* **10** [Found: *m/z* 305.138. $C_{15}H_{20}F_3O_3$ (M + 1) requires *m/z* 305.136]; $\nu_{max}(CHCl_3)/cm^{-1}$ 2960, 1740, 1270, 1190 and 1155; $\delta_H(CDCl_3$; 500 MHz) 1.3–2.1 (16 H, m, CH_2 × 8), 3.08 (1 H, q, *J* 7.5, 6-H), 3.18 (1 H, br t, *J* 7.5, 2-H) and 4.70 (1 H, dd, *J* 1.5 and 7.5, 7-H).

For *compound* **11** [Found: *m/z*, 305.134. $C_{15}H_{20}F_3O_3$ (M + 1) requires *m/z*, 305.136]; $\nu_{max}(CHCl_3)/cm^{-1}$ 2960, 1740, 1310 and 1190; $\delta_H(CDCl_3$; 500 MHz) 1.3–2.2 (16 H, m, CH_2 × 8), 2.73 (1 H, m, 6-H), 3.31 (1 H, br t, *J* 8, 2-H) and 4.47 (1 H, d, *J* 3, 7-H).

rel-(1R,6R,7S)-7-*Methoxy*-5,9-*dioxo*-6-*trifluoromethyl*-2,4-*dioxabicyclo*[4.4.0]*decane*-3-*spirocyclohexane* **12**.—A solution of compound **3a** (71 mg, 0.3 mmol) and 1-methoxy-3-(trimethylsiloxy)buta-1,3-diene (103 mg, 0.6 mmol) in toluene (2 cm^3) was treated at 10 kbar at room temperature for 42 h. The residue obtained after evaporation of the solvent was dissolved with tetrahydrofuran (5 cm^3). KF (70 mg, 1.2 mmol) was added to the solution and the mixture was stirred at room temperature for 19 h. The reaction mixture was diluted with water and extracted with diethyl ether. The organic layer was washed with water and dried over $MgSO_4$. The residue obtained after evaporation of the solvent was chromatographed on silica gel [hexane–AcOEt (3:1)] to give the *title compound* **12** as prisms

(82 mg, 82%); m.p. 83.0–84.5 °C (from ether–hexane) (Found: C, 53.3; H, 5.8. $C_{15}H_{19}F_3O_5$ requires C, 53.55; H, 5.7%); $\nu_{max}(CHCl_3)/cm^{-1}$ 2960, 1740 and 1735; $\delta_H(CDCl_3$; 500 MHz) 1.20–2.00 (10 H, m, $CH_2 \times 5$), 2.62 (1 H, dd, *J* 3 and 16, 8-H), 2.77 (1 H, d, *J* 16, 10-H), 2.88 (1 H, d, *J* 16, 8-H′), 2.92 (1 H, dd, *J* 6 and 16, 10-H′), 3.33 (3 H, s, OMe), 4.41 (1 H, dt, *J* 2 and 3, 7-H) and 4.88 (1 H, ddd, *J* 2, 3 and 6, 1-H).

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