Use of 1,3-Dioxin-4-ones and Their Related Compounds in Synthesis. Part 28 [1]. Asymmetric de Mayo Reactions Using Chiral Spirocyclic Dioxinones

Masayuki Sato*, Yoshito Abe, Kazuhisa Takayama,
Keiko Sekiguchi and Chikara Kaneko*

Pharmaceutical Institute, Tohoku University,
Aobayama, Sendai 980, Japan

Naoko Inoue (nee Suzaki), Toshio Furuya and Noriyoshi Inukai

Tsukuba Research Laboratories, Yamanouchi Pharmaceutical Co. Ltd.,
21 Miyukigaoka, Tsukuba, Ibaragi 305, Japan

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The use of rigid spirocyclic dioxinones having l-menthone as the chiral auxiliary as the enones in the photo[2+2]cycloaddition reactions opened novel methods for obtaining enantiomerically pure compounds, such as iridoids. Convex side preference of the sofa-conformation of these dioxinones in the photoaddition to cyclopentene increases up to 100% by introducing either a bulky substituent or 5-hexenyl group at the 3-position to these dioxinones and, hence, highly asymmetric inter- and intramolecular de Mayo reactions have been disclosed.

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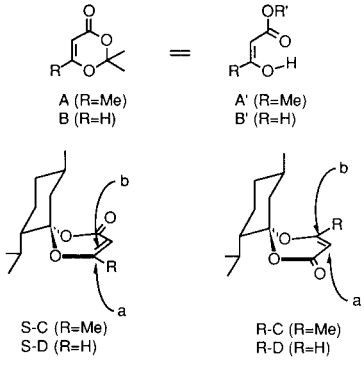
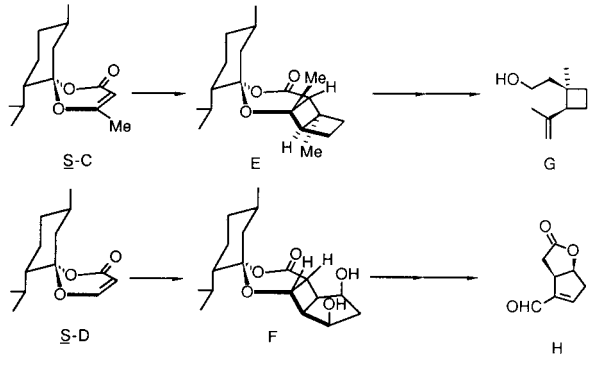
The [2+2]cycloaddition of enones and enone-like chromophores to olefins is by far the most widely employed photochemical reaction in organic synthesis [3]. Most obviously it constitutes a major route to products containing the cyclobutane moiety. Enol derivatives or even tautomers of β-dicarbonyls act as the enone component in the de Mayo variant [4], in which the photoadducts undergo retro-aldol cleavage of the cyclobutane and the method is applicable to the synthesis of complex molecules. The use of achiral dioxinones, **A** [5] and **B** [6,7], as the alternatives for acetoacetates and formylacetates (**A'** and **B'**: both of which are incapable of photoaddition to olefins) has further broadened the scope of the de Mayo reaction.



Scheme 1

The use of the rigid spirocyclic dioxinones **C** [8] and **D** [9] as the chiral enones has recently brought about much interest, because it provides the ready access to diastereoisomeric, and ultimately enantiomeric products. The preferential a-side photoaddition of olefins to these spiro[6.6]dioxaundecene system has been found and its reason is explained by the sofa-conformation of the dioxinone ring, whose more exposed a-side (convex side) accepts the olefins more preferentially than b-side (concave side) [8,9]. In the work along this line, (+)-grandisol (**G**) [8] and the (+)-Corey lactone analogue **H** [10] were synthesized from *S*-**C** (R = Me) and *S*-**D** (R = H), respectively. However, one demerit of the asymmetric de Mayo reactions mentioned above is that the diastereomeric excess (de) is, though high, not 100%. Thus, in the synthesis of the Corey lactone analogue **H** the addition step proceeded in de 82% by irradiation at room temperature [10] and in the case of grandisol (**G**), de 90% even the irradiation was performed at -78° [8].



Scheme 2

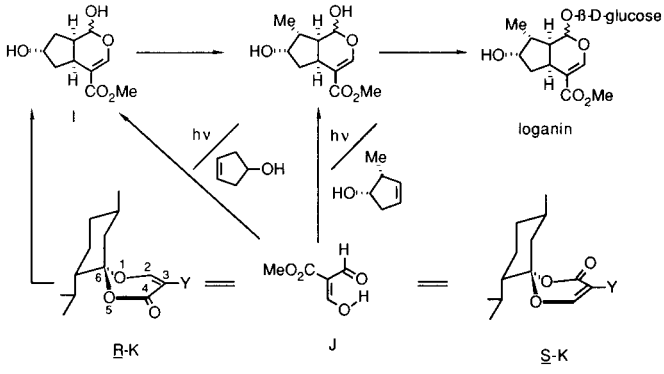
In this paper, we wish to report how one can attain the complete diastereofacial selectivity of the above photoaddition reactions by modifying the dioxinone chromophore. In order to economise space, the paper will be divided into two parts dealing with 1) intermolecular and 2) intramolecular de Mayo reactions.

How to Improve the Diastereofacial Selectivity of the Intermolecular de Mayo Reaction by Modifying the Dioxinone Chromophore.

Demuth *et al.* originally pointed out that the rigid spirocyclic dioxacyclohexenones ***S*-C** and ***R*-C**, when reacted with cyclic and acyclic alkenes, give rise preferentially a-side addition with magnitude of asymmetric induction (a/b) up to 10:1 by irradiation at -78° [8]. We also have observed the preferential a-side addition with the magnitude of induction (de, *ca.* 71%) in the photoaddition (room temperature) of 2,3-unsubstituted dioxinones, ***S*-D** and ***R*-D**, with cyclopentene [9]. It should be noted that these additions, if cycloalkenes were employed, gave in almost complete selectivity *cis-anti-cis* fused products.

Having these in mind, we were interested in applying this method to the synthesis of iridoids, because penstemid [11] and didrovaltrate [12] having iridoid skeleton have been recently found to show antitumor activity.

Synthesis of iridoids has been accomplished for the first time by Büchi *et al.* [13] using methyl diformylacetate (**J**) as the enone and 3-cyclopentene-1-ol as the olefin by an application of de Mayo reaction. The fact that highly regio- and stereoselective transformation of the adduct **I** thus obtained to (±)-loganin [13], -sweroside [14], and -secologanin [14] indicates that **I** is a versatile synthon for iridoids, at least in racemic series.

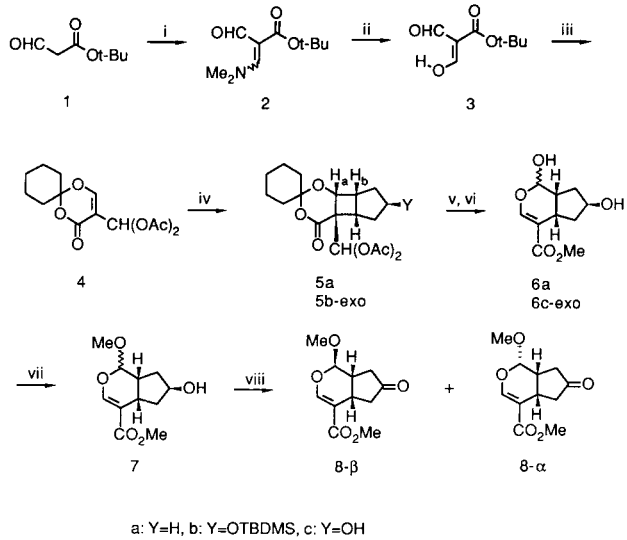


Scheme 3. Y=CHO or equivalent.

While other methods are also available [15-18], the enantioselective route to iridoids is use of chiral olefins, *e.g.* (1*S*,2*R*)-2-methyl-3-cyclopentene-1-ol in Büchi's method as exemplified in the synthesis of (+)-loganin [19] and (+)-sarracenin [20]. This method, however, suffers considerable drawbacks: 1) multistep sequences for the preparation of the chiral olefins which had to be used in a larger quantity, 2) poor regio- and enantioselectivities, and 3) inapplicability to the synthesis of an optically active **I** which necessarily requires achiral 3-cyclopenten-1-ol. Clearly, if an enantiomerically pure spirocyclic dioxinone, **K**, Y = CHO, or equivallent) which acts like diformylacetates **J** could be prepared readily in a preparative scale, the method would constitute a more efficient alternative to the enantioselective synthetic method of **I** and hence of optically active iridoids.

In the preliminary study along this line, we first examined the photoaddition of achiral enone **4**. It is because in the photoaddition to cyclopentenes, the present methodology requires added to an obvious a-side preference, either high *endo*/*exo*- or *exo*/*endo* preference.

The desired model compound **4** was synthesized from *t*-butyl formylacetate (**1**) [21] in *ca.* 60% overall yield by three steps shown in Scheme 4. The photoaddition of **4** to cyclopentene proceeded efficiently in ethyl acetate by irradiation at 300 nm and gave a single adduct **5a** in 86% isolated yield. The *cis-syn-cis* structure of **5a** is deduced by inspection of ^{1}H nmr coupling constant (6.0 Hz) between H-a and H-b and was finally confirmed by X-ray crystallographic analysis (*cf.* Figure 1).



Scheme 4. Reagents and conditions: i; $Me_2NCH(OMe)_2$, room temp., ii, 1 M NaOH, 0 °C, iii; cyclohexanone, conc. H_2SO_4, Ac_2O, 0 °C, iv; cyclopentene or 3-cyclopentene-1-ol TBDMS ether (10 equiv.), 300 nm, room temp., v; H_2O , room temp., p-TsOH (cat. amount), vi; CH_2N_2 / ether, vii; Amberlite IR -120 B (H^+) / MeOH, viii; PCC / CH_2Cl_2.

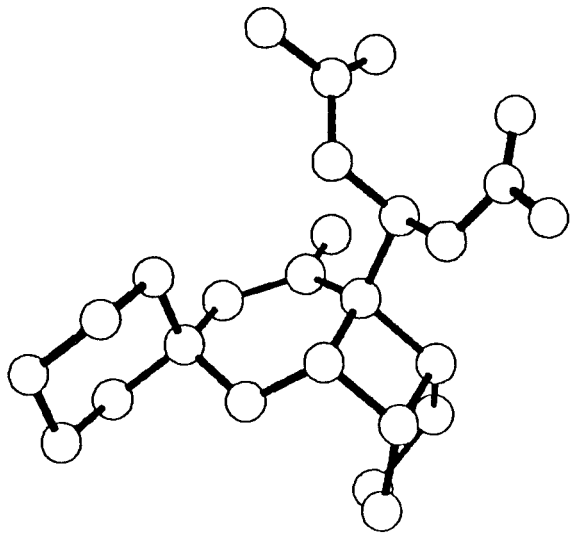
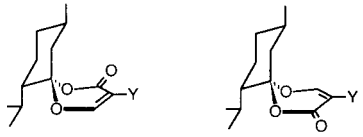


Figure 1. Molecular structure of **5a**.

As shown in Scheme 4, the adduct was transformed to the deoxy bicyclic compound **6a** in 83% yield. When *t*-butyldimethysilyl (TBDMS) ether of 3-cyclopenten-1-ol was used as the olefin, two adducts **5b** were obtained in 92% yield as a mixture of diastereomers in a ratio of *ca.* 9:1 (judged by hplc). Since *cis-syn-cis* structures were verified by nmr ($J_{H\text{-}a,H\text{-}b}$ = 6.0 Hz) for both adducts, it is obvious that the adducts are stereoisomers concerning the silyloxy group and the major adduct is **5b**-*exo* and the minor one is **5b**-*endo*. By sequential reactions shown in Scheme 4, The adduct **5b** (a mixture of two isomers) was transformed to the pyran derivative **7** whose pyridinium chlorochromate (PCC) oxidation gave the ketone **8**. Two anomers of **8** were separated by column chromatography to give the major and minor products in 54 and 35% yields, respectively. The nmr coupling (d, J = 7.0 Hz) of the methine proton in the acetal moiety of the major product, **8**-β, showed that the methoxy group is *cis* configuration relative to the adjacent proton.

Encouraged by the above model study, the corresponding chiral spirocyclic dioxinones, *S*-**9** and *R*-**9**, were synthesized from **3** and *l*-menthone by the same method shown in Scheme 4. Diastereomers of **9** (*ca.* 1:1 ratio) were separated readily by fractional recrystallization from pentane to give the less *S*-**9** and the more polar dioxinones *R*-**9**. Both compounds, when hydrogenated over palladium charcoal, gave the corresponding 3-methyl derivatives *S*-**10** and *R*-**10**. Since 6*S*-isomers of 2,3-unsubstituted dioxinones and their 2-methyl derivatives are always less polar than the 6*R*-isomers [8,9,22,23], it is evident that the less polar dioxinones, *S*-**9** and *S*-**10**, have 6*S*-configuration and the more polar ones 6*R*-configuration, *R*-**9** and *R*-**10**.

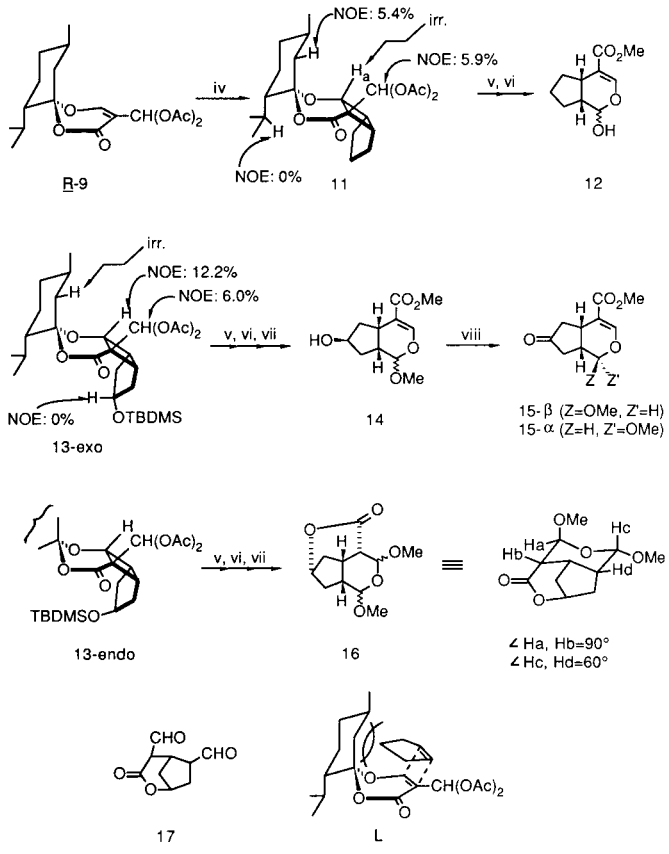


S-9 (S-10) R-9 (R-10)

Scheme 5. 9: Y= $CH(OAc)_2$, 10:Y=Me

Since the a-side preference in these dioxinones are obvious, the more polar dioxinones *R*-**9** was photoadded to cyclopentene. As a result, single adduct **11** having *cis-syn-cis* structure ($J_{Ha,Hb}$ = 6.0 Hz) was obtained in 86% yield as the sole product. By NOE study depicted in formula **11**, the structure was determined as being formed by the a-side addition. The adduct was transformed to **12** in the same manner as in racemic series (*cf.* **5** → **6** in Scheme 4).

Using the cyclopentenol (TBDMS ether) as the olefin, two adducts, (**13**-exo and **13**-endo), were obtained in a ratio of *ca.* 15:2 (judged from hplc). By silica gel column chromatography, the less polar adduct **13**-*exo* was readily



Scheme 6. Reagents and conditions: iv-viii are the same as those in scheme 4.

separated from the more polar minor adduct **13**-*endo* and its isolated yield was 52%. The structure of **13**-*exo* was verified by NOE study depicted in formula **13**-*exo*. By the same sequential reactions as in the case of **5b** to **6c**, the aimed chiral cyclopenta[*c*]pyran-4-carboxylate (**14**) was obtained as a mixture of α- and β- anomers (ratio of α/β = 1:2 from 500 MHz ^{1}H nmr) in 82% overall yield from **13**-*exo*. By PCC oxidation, the mixture gave readily separable ketones **15**. The β-anomer **15**-β and α-anomer **15**-α were obtained in 60 and 36% yields, respectively.

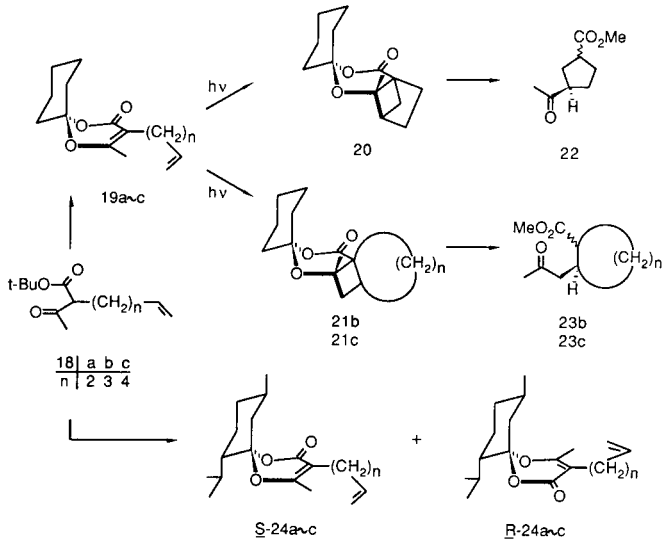
It should be noted that the same sequential reactions, if applied to the minor adduct **13**-*endo*, afforded rather unexpected product, to which we tentatively assign the following tricyclic structures **16**. Formation of this rather abnormal product is, probably, explained by assuming that the minor adduct is **13**-*endo* (again, a-side addition product) and hence the cyclopentanol formed by the deblocking of the silyl group gave the lactone **17** being the precursor of the final product **16**. The tentatively assigned stereostructure depicted in Scheme 6 well explains the characteristic nmr signals of **16** in which one methine proton (Ha) appears as singlet while the other one (Hc) as doublet with a small coupling ($J_{Hc,Hd}$ = 3.0 Hz).

Compared with an exclusive *anti*-addition as observed in the corresponding 2,3-unsubstituted and 2-methylated dioxinones **C** and **D**, remarkable *syn*-preference of **4** in the photoaddition step seems to need comments. We assume that the bulkiness of diacetoxymethyl group of **4** is the reason for it. This also explains nicely that why the use of **9** instead of **C** or **D** enhances the a-side preference (b-side addition product is not detected), because the b-side attack with *cis-syn-cis* preference is prohibited to occur due to severe steric hindrance (*cf.* **L** in Scheme 6).

How to Improve the Diastereofacial Selectivity of the [2+2]photoaddition Reaction by use of Intramolecular Variant.

In the foregoing section, we described highly diastereoselective intermolecular photo[2+2]addition using chiral spirocyclic dioxinones having a bulky diacetoxymethyl group at the 3-position (**K**, Y = $CH(OAc)_2$) and its application for the synthesis of optically active iridoids. In this section, we describe the photoaddition of chiral spirocyclic dioxinones having ω-alkenyl group at 3-position [*S*- and *R*-**24**] in order to see how the diastereoselectivity of the addition depends upon the length of the methylene chain. It should be noted that in the intramolecular valiant the regio- and stereoselectivities are substantially reduced owing to geometrical constraints imposed on the reaction sites [24,25].

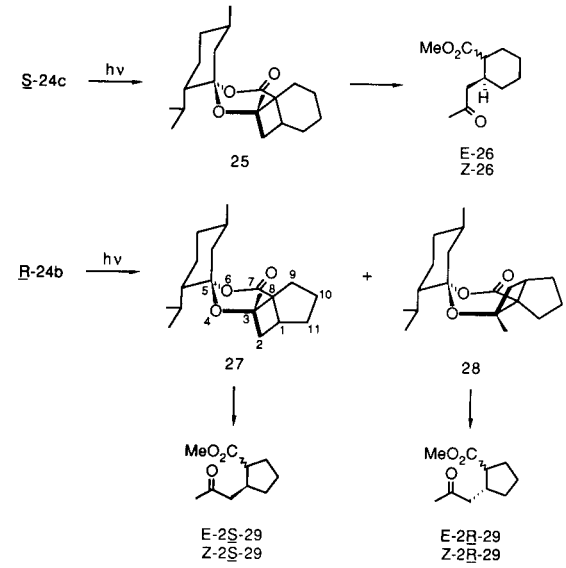
In order to clarify how the selectivity for parallel or cross addition depends upon the length of the methylene chain, achiral dioxinones **19a ~ c** were prepared as outlined in Scheme 7.



Scheme 7

Thus, alkylation of *t*-butyl acetoacetate with corresponding ω-alkenyl bromides under basic conditions followed by dioxinone formation gave the achiral dioxinones **19a-19c**. Three dioxinones thus obtained were then irradiated at 300 nm in a mixture of acetone and acetonitrile. While irradiation of **19a** gave the cross adduct **20**, compounds **19b** and **19c** under identical conditions afforded the corresponding parallel adducts **21b** and **21c**. The structures of the photoproducts were determined not only from nmr spectra but also by their transformations to the ring-opened keto esters **22**, **23b** and **23c** whose structures were determined by nmr spectra. The keto esters obtained were mixtures of both *Z*-and *E*-isomers, as the latters always being the major isomers. Obviously, the regioselectivity observed in the above reactions is the one as expected from the so-called rule of five [24,26].

Next, we examined the intramolecular cycloaddition reactions by using the 6*S*-isomer, *S*-**24**, as the chiral dioxinones, which could be synthesized from **18** and *l*-menthone in the same manner from cyclohexanone as the achiral series. The diastereomers obtained in each case were separated chromatographically to the major (*S*-series) and minor ones (*R*-series). Though photolysis of *S*-**24a** proceeded only slowly and after prolonged irradiation resulted in a complex mixture, the same photolysis if applied to *S*-**24c** afforded a single adduct **25** in 90% yield in a comparable rate as in the corresponding achiral compounds **19c** → **21c**. The stereochemistry of **25** was determined as the parallel adduct formed by a-side addition from X-ray crystallographic analysis (*cf.* Figure 2). The adduct **25**, on hydrolysis followed by methylation, afforded the 2-acetonylcyclohexanecarboxylate (**26**) as a mixture of *E*- and *Z*-isomers both having 2*S*-configuration.



Scheme 8

The same photolysis of *S*-**24b**, though proceeded in much faster rate than that of *S*-**24c**, resulted in the formation of the two adducts **27** and **28** (*ca.* 1:1 ratio) in a total

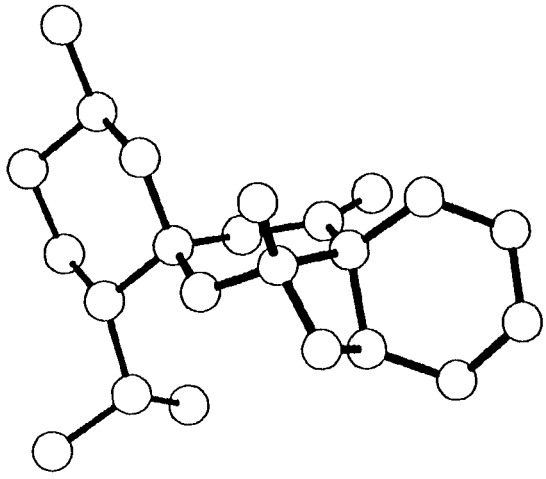


Figure 2. Molecular structure of **25**.

yield of 70%. The isomer **27** (more polar) and **28** (less polar) were assigned to be adducts from the a-side and b-side, respectively, by the comparison of the ^{1}H nmr data with that of the adduct **25**. Following the procedure for preparation of **26**, the enantiomeric cyclopentane carboxylates 2*S*-**29** and 2*R*-**29** were prepared from **27** and **28**, respectively. The lack of selectivity in the photocycloaddition of *S*-**24b** probably reflects the shortness of the methylene chain which brings about extra geometrical constraint imposed on the reaction sites. This constraint, then, determines the preferential site by kinetic control irrespective of the conformation of the dioxinone chromophores. The high rate of photoaddition of *S*-**24b** over that of *S*-**24c** supports the above views. Since *S*-**24c** shows highly preferential a-side addition, the methodology previously established in achiral series for highly stereoselective construction of complex carbocyclic system can evidently be extended in the chiral series if one uses chiral spirocyclic dioxinones as the enones, so long as the methylene chain is 4.

Conclusions.

Two important informations concerning to the use of chiral spirocyclic dioxinones as the enones in the photo[2+2]cycloaddition were obtained in the present study which provided almost complete a-side selectivity: 1) an introduction of a bulky substituent at the 3-position, which prevents the *cis-syn-cis* addition (relative to the substituent) of the olefins, would enhance a-side preference to de 100% and 2) an intramolecular addition of the spirocyclic dioxione having 5-hexenyl chain at the 3-position gives rise to the parallel adduct with complete a-side preference. The results thus obtained suggest strongly that use of the corresponding 3-substituted dioxinones in the photoaddition reactions (both inter- and intramolecular) would also provide novel methods for the synthesis of enantiomerically pure compounds. The study along this line of works are in progress and will be reported in due course.

EXPERIMENTAL

All melting points were determined on a micro-hot stage (Yanagimoto) and are uncorrected. Optical rotations were measured with a JASCO DIP-340 digital polarimeter. Infrared (ir) spectra were recorded on a JASCO A-102 spectrometer and proton nuclear magnetic resonance (^{1}H nmr) spectra on a JNM-PMX60SI or JEOL JNM-FX500 spectrometer (with tetramethylsilane as an internal standard). High-resolution mass spectra (ms) were taken with a JEOL JMS-OISG-2 spectrometer. Silica gel used for column chromatrography was Wakogel C-200. TLC was performed on Merck Kieselgel 60 F254. High-pressure liquid chromatography (HPLC) was performed with a Waters μ-Porasil column (30 cm). Medium-pressure liquid chromatography was performed with a Merck Lobar column (LiChroprep Si 60). The ratio of solvent mixtures for chromatography is shown as volume/volume.

Irradiation Conditions.

The photoreactions was carried out at room temperature in a quartz vessel with Rayonet RPR 3000Å lamps.

t-Butyl 2-Dimethylaminomethyleneformylacetate (**2**).

A solution of *t*-butyl formylacetate (**1**) was prepared by heating of formylated Meldrum's acid (17.2 g, 0.1 mole) and *t*-butyl alcohol (8.88 g, 0.12 mole) in toluene (200 ml) for 35 minutes according to the literature [6]. *N,N*-Dimethylformamide dimethyl acetal (14.3 g, 0.12 mole) was added to the above solution under ice-cooling and the whole was kept standing at room temperature for 5 hours. The solvent was evaporated off *in vacuo* and the residue was purified by column chromatography (silica gel, 150 g, ethyl acetate) to give crystalline **2**, yield, 12.0 g (70% based on formylated Meldrum's acid). A portion was recrystallized from ether-pentane to give pale yellow leaves, mp 45-46°; ir (chloroform): 1682, 1635 cm^{-1}; ^{1}H nmr (chloroform-d$_1$): δ 1.48 (9H, s), 3.20 (6H, br s), 7.66 (1H, s), 9.66 (1H, s).

Anal. Calcd. for $C_{10}H_{17}NO_3$: C, 60.28; H, 8.60; N, 7.03. Found: C, 59.87; H, 8.71; N, 7.14.

t-Butyl Diformylacetate (**3**).

Compound **2** (11.97 g, 0.7 mole) was added to an ice-cooled solution of sodium hydroxide (3.08 g, 0.77 mole) in water (100 ml) with stirring. After 10 minutes, the solution was acidified with 10*N* hydrochloric acid and extracted with ether. The organic layer was washed with brine, dried over magnesium sulfate, and evaporated *in vacuo* to give essentially pure **2** (9.52 g, 79%), mp 44-46°. A portion was recrystallized from pentane to give leaves of mp 45-46°; ir (chloroform): 1705, 1655, 1585 cm^{-1}; ^{1}H nmr (chloroform-d$_1$): δ 1.52 (9H, s), 9.07 (2H, s), 12.70-14.30 (1H, br s).

Anal. Calcd. for $C_8H_{12}O_4$: C, 55.80; H, 7.03. Found: C, 55.34; H, 6.70.

3-Diacetoxymethyl-4-oxo-1,5-dioxaspiro[5.5]undec-2-ene (**4**).

Concentrated sulfuric acid (1.50 g, 15 mmoles) was added portionwize to a mixture of **3** (5.16 g, 30 mmoles), cyclohexanone (8.82 g, 90 mmoles), and acetic anhydride (9.18 g, 90 mmoles) under stirring at -5°-0°. The mixture was kept standing in a

refrigerator (0°) overnight. The mixture was poured into an ice-water containing sodium bicarbonate (10 g) and the whole was stirred for 45 minutes. The mixture was extracted with ether. The ether layer was dried over magnesium sulfate and evaporated. Hexane was added to the residue and the crystals were collected by suction to give **4** (6.0 g, 67%), mp 99-100° (prisms from ether); ir (chloroform): 1770, 1735, 1640 cm^{-1}; ^1H nmr (chloroform-d_1): δ 1.33-2.30 (10H, m), 2.16 (6H, s), 7.44 (2H, s).

Anal. Calcd. for $C_{14}H_{18}O_7$: C, 56.37; H, 6.08. Found: C, 56.15; H, 6.11.

7-Diacetoxymethyl-6-oxo-3,5-dioxatricyclo[6.3.0.$0^{2,7}$]undecane-4-spirocyclohexane (**5a**).

After bubbling argon for 5 minutes, a solution of **4** (298 mg, 1 mmole) and cyclopentene (1.36 g, 20 mmoles) in ethyl acetate (25 ml) was irradiated for 28 hours. The solvent was evaporated off *in vacuo* and the residue was purified by column chromatography using hexane/ethyl acetate (5:1) as an eluent to give **5a** (277 mg, 75%). Recrystallization from ether gave prisms of mp 141-142°; ir (chloroform): 1779, 1730 cm^{-1}; ^1H nmr (chloroform-d_1): δ 1.6-2.5 (16H, m), 2.03, 2.13 (each 3H, s), 2.6-3.1 (2H, m), 4.67 (1H, t, J = 4.5 Hz), 7.13 (1H, s).

Anal. Calcd. for $C_{19}H_{26}O_7$: C, 62.28; H, 7.15. Found: C, 62.17; H, 7.16.

7-Diacetoxymethyl-10-*t*-butyldimethylsilyloxy-6-oxo-3,5-dioxatricyclo[6.3.0.$0^{2,7}$]undecane-4-spirocyclohexane (**5b**-*exo*).

After bubbling argon for 5 minutes, a solution of **4** (89.5 mg, 0.3 mmole) and 4-*t*-butyldimethylsiloxycyclopent-1-ene (920 mg, 3 mmoles) in ethyl acetate (16 ml) was irradiated for 12 hours (condition A). The solvent was evaporated off *in vacuo* and the residue was purified by column chromatography using hexane/ethyl acetate (10:1) to give a diastereomeric mixture **5b** (85.3 mg, 57%) as an oil. The ratio of the mixture was determined to be 1:9 by hplc analysis; **5b**-*exo*; ir (chloroform): 1782, 1733 cm^{-1}; ^1H nmr (chloroform-d_1): δ 0.05 (6H, s), 0.89 (9H, s), 2.06, 2.15 (each 3H, s), 3.00 (2H, m), 4.66 (2H, m), 7.16 (1H, s); accurate mass 496.2462; $C_{25}H_{40}O_8Si$ requires M^+, 496.2490.

Methyl 5-Hydroxy-4-oxabicyclo[4.3.0]non-2-ene-2-carboxylate (**6a**).

A solution of **5a** (286 mg, 0.86 mmole), *p*-toluenesulfonic acid (81.3 mg, 0.43 mmole), and one drop of water in tetrahydrofuran (5 ml) was stirred for 4 days at room temperature. The solution was dried over magnesium sulfate and evaporated *in vacuo*. The residue was dissolved in ether and treated with excess diazomethane under ice-cooling. After evaporation of the solvent, the residue was purified by column chromatography using hexane/ethyl acetate (2:1) to give **6a** (140 mg, 83%) as an oil. As judged from the ^1H nmr spectrum, the product was a mixture (ratio, *ca.* 6:1) of two isomers; ir (chloroform): 3660-3150, 1705, 1635 cm^{-1}; ^1H nmr (chloroform-d_1): δ 1.00-3.10 (8H, m), 3.36-3.70 (1H, brs), 3.73 (3H, s), 4.76-5.06 (6/7 H br s), 5.30-5.50 (1/7 H, m), 7.50 (1H, br s); accurate mass 198.0890; $C_{10}H_{14}O_4$ requires M^+, 198.0891.

Methyl 8-Hydroxy-5-methoxy-4-oxabicyclo[4.3.0]non-2-ene-2-carboxylate (**7**).

A solution of **5b** (414 mg, 0.48 mmole), *p*-toluenesulfonic acid (46 mg, 0.24 mmole), and water (one drop) in tetrahydrofuran (5 ml) was stirred at room temperature for 4 hours. The solution was dried over magnesium sulfate and evaporated *in vacuo*. The residue was treated with diazomethane in ether under ice-cooling. After evaporation of the solvent, the residue was dissolved in absolute methanol (10 ml). Ion exchange resine (IR-120B, 1 g) was added to the solution and the whole was stirred for 12 hours at room temperature. After evaporation of the solvent *in vacuo* the residue was purified by column chromatography using ethyl acetate/dichloromethane (2:1) to give **7** as a mixture of two isomers (91 mg, 83%) as an oil; ir (chloroform): 3650-3150, 1703, 1635 cm^{-1}; ^1H nmr (chloroform-d_1): δ 1.20-3.33 (7H, m), 3.42 (1H, s, OMe), 3.49 (2H, s, OMe), 3.70 (3H, s, CO_2Me), 4.13-4.56 (1.7 H, m), 4.56-4.95 (0.3 H, m), 7.42 (1H, br s); accurate mass 228.0994; $C_{11}H_{16}O_5$ requires M^+, 228.0997.

Methyl 5-Methoxy-8-oxo-4-oxabicyclo[4.3.0]non-2-ene-2-carboxylate (**8**-α and **8**-β).

A solution of **7** (80 mg, 0.35 mmole) in dichloromethane (2 ml) was added to a stirred mixture of pyridinium chlorochromate (161 mg, 0.75 mmole) in dichloromethane (5 ml). The whole was stirred at room temperature for 3 hours. The mixture was passed through short silica gel column (1 g) and then evaporated *in vacuo*. The residue was purified by chromatography using hexane/ether (3:1) as an eluent to give **8**-β (solid, 43 mg, 54%) and then **8**-α (oil, 28 mg, 35%).

Compound **8**-β had mp 88~89° (needles from pentane/ether); ir (chloroform): 1745, 1705, 1635 cm^{-1}; ^1H nmr (chloroform-d_1): δ 2.00-3.40 (7H, m), 3.50 (3H, s, OMe), 3.69 (3H, s, CO_2Me), 4.73 (1H, d, J = 5.0 Hz, C_5-H), 7.14 (1H, br s, C_3-H).

Anal. Calcd. for $C_{11}H_{14}O_5$: C, 58.40; H, 6.24. Found: C, 58.39; H, 6.24.

Compound **8**-α had ir (chloroform): 1748, 1705, 1640 cm^{-1}; ^1H nmr (chloroform-d_1): δ 2.20-3.20 (7H, m), 3.37 (3H, s, OMe), 3.70 (3H, s, CO_2Me), 4.95 (1H, d, J = 3.0 Hz, C_5-H), 7.47 (1H, br s, C_3-H); accurate mass 226.0850; $C_{11}H_{14}O_5$ requires M^+, 226.0840.

Anal. Calcd. for $C_{11}H_{14}O_5$: C, 58.40; H, 6.24. Found: C, 58.50; H, 6.27.

(6*S*,7*S*,10*R*)- and (6*R*,7*S*,10*R*)-3-Diacetoxymethyl-7-isopropyl-10-methyl-4-oxo-1,5-dioxaspiro[5.5]undec-2-ene (*S*-**9** and *R*-**9**).

To a solution containing *t*-butyl diformylacetate (**3**, 516 mg, 3 mmoles), *l*-menthone (1.39 g, 9 mmoles) and acetic anhydride (1.53 g, 15 mmoles) was added concentrated sulfuric acid (304 mg, 3 mmoles) under cooling (-20° to -10°) and the whole was kept in a refrigerator (0°) for 37 hours. The mixture was poured on to a stirred ice-water containing sodium bicarbonate (3.02 g, 36 mmoles). After neutralization had completed, the mixture was extracted with ether. The ether layer was washed with water and dried over magnesium sulfate. The residue obtained by evaporation of the solvent was chromatographed over silica gel (50 g). Elution by hexane-ethyl acetate (10:1) gave 528 mg (50%) of a mixture of diastereomers (ratio: *ca.* 1:1 by hplc). By fractional recrystallization from pentane, two diastereomers *R*-**9** (the less soluble diastereomer) and *S*-**9** (the more soluble one) were obtained.

Compound *S*-**9** had mp 108-109° (needles from pentane); $[\alpha]_D^{24}$ -17.8° (c = 1.0, chloroform); ir (chloroform): 1768, 1740, 1640 cm^{-1}; 500 MHz ^1H nmr (chloroform-d_1): δ 0.91 (6H, d, J = 6.6 Hz, isopropyl-Me and C_{10}-Me), 0.96 (3H, d, J = 7.0 Hz, isopropyl-Me), 1.09 (1H, t, J = 13.2 Hz, axial-C_{11}-H), 2.12, 2.13 (each 3H, s, 2 x OAc), 2.20 (1H, m, C*H*Me_2), 2.55 (1H, ddd, J = 13.2, 3.8, 2.3 Hz, equatorial-C_{11}-H), 7.39, 7.40 (each 1H, s, C*H*$(OAc)_2$ and C_2-H).

Anal. Calcd. for $C_{18}H_{26}O_7$: C, 61.00; H, 7.40. Found: C, 60.75; H, 7.10.

Compound *R*-**9** had mp 90-97° dec, leaves from ether-pentane; $[\alpha]_D^{28}$ -28.2° (c = 0.66, chloroform); ir (chloroform): 1768, 1739, 1641 cm^{-1}; 500 MHz ^1H nmr (chloroform-d): δ 0.86 (3H, d, J = 6.6 Hz, isopropyl-Me), 0.91 (3H, d, J = 6.6 Hz, C_{10}-Me), 0.95 (3H, d, J = 7.0 Hz, isopropyl-Me), 1.17 (1H, t, J = 13.6 Hz, axial-C_{11}-H), 2.13, 2.14 (each 3H, s, 2 x Ac), 2.32 (1H, m, C*H*Me_2), 2.56 (1H, ddd, J = 13.6, 3.8, 1.6 Hz, equatorial-C_{11}H), 7.39, 7.40 (each 1H, s, C*H*(OAc) and C_2-H).

Anal. Calcd. for $C_{18}H_{26}O_7$: C, 61.00; H, 7.40. Found: C, 60.73; H, 7.40.

(6*S*,7*S*,10*R*)-7-Isopropyl-3,10-dimethyl-4-oxo-1,5-dioxaspiro[5.5]-undec-2-ene (*S*-**10**).

Catalytic hydrogenation of *S*-**9** (80.5 mg, 0.23 mmole) in methanol (5 ml) over 10% Pd-C (40 mg) at 1 atmosphere at room temperature followed by purification of the product by ptlc [hexane-ethyl acetate (30:1)] gave 23.6 mg (43%) of *S*-**10**; ir (chloroform): 1720, 1650 cm^{-1}; ^1H nmr (chloroform-d_1): δ 0.89 (3H, d, J = 6.6 Hz, C_{10}-Me), 0.91 (3H, d, J = 7.0 Hz, isopropyl-Me), 0.97 (3H, d, J = 7.0 Hz, isopropyl-Me), 1.02 (1H, t, J = 13.0 Hz, axial-C_{11}-H), 1.77 (3H, d, J = 1.1 Hz, C_3-Me), 2.25 (1H, m, C*H*Me_2), 2.63 (1H, ddd, J = 13.0, 3.3, 2.1 Hz, equatorial-C_{11}-H), 7.39, 7.40 (each 1H, s, C*H*$(OAc)_2$, C_2-H); accurate mass 238.1555; $C_{14}H_{22}O_3$ requires M^+, 238.1568.

(6*R*,7*S*,10*R*)-7-Isopropyl-3,10-dimethyl-4-oxo-1,5-dioxaspiro[5.5]-undec-2-ene (*R*-**10**).

According to the preparation of *S*-**10** from *S*-**9**, compound *R*-**10** was prepared in 25% yield from *R*-**9**, oil; ir (chloroform): 1720, 1650 cm^{-1}; ^1H nmr (chloroform-d_1): 500 MHz δ 0.87 (3H, d, J = 7.0 Hz, isopropyl-Me), 0.89 (3H, d, J = 6.6 Hz, C_{10}-Me), 0.94 (3H, d, J = 7.0 Hz, isopropyl-Me), 1.09 (1H, t, J = 13.0 Hz, axial-C_{11}-H), 1.78 (3H, d, J = 1.5 Hz, C_3-Me), 2.33 (1H, m, C*H*Me_2), 2.64 (1H, ddd, J = 13.6, 3.7, 2.2 Hz, equatorial-C_{11}-H), 6.93 (1H, d, J = 1.5 Hz, C_2-H); accurate mass 238.1603; $C_{14}H_{22}O_3$ requires M^+, 238.1568.

(1*R*,2*R*,2′*S*,4*R*,5′*R*,7*S*,8*S*)-7-Diacetoxymethyl-6-oxo-3,5-dioxatricyclo[6.3.0.$0^{2,7}$]undecane-4-spiro(2′-isopropyl-5′-methyl)cyclohexane (**11**).

A solution of **9** (354 mg, 1.0 mmole) and cyclopentene (1.36 g, 20 mmoles) in a mixture of hexane-ethyl acetate (3:1, 45 ml) was irradiated for 12 hours. The residue obtained after evaporation of the solvent was subjected to column chromatography (silica gel, 30 g). Elution with hexane-ethyl acetate (10:1) gave 374 mg (89%) of **11**, whose de was determined as $\geq$93% by hplc; **11**, oil; ir (chloroform): 1780, 1728 cm^{-1}; ^1H nmr (chloroform-d_1): 500 MHz δ 0.91 (3H, d, J = 7.2 Hz, isopropyl-Me), 0.94 (3H, d, J = 6.2 Hz, C_{10}-Me), 0.94 (3H, d, J = 7.2 Hz, isopropyl-Me), 1.21 (1H, t, J = 13.5 Hz, axial-C_{11}-H), 2.09, 2.16 (each 3H, s, 2 x OAc), 2.32 (1H, m, C*H*Me_2), 2.61 (1H, ddd, J = 14.2, 3.2, 2.1 Hz, C_1-H), 2.8-2.9 (2H, m, C_7-H, C_8-H), 4.53 (1H, dd, J = 6.3, 3.2 Hz, C_2-H). $[\alpha]_D^{19}$ +9.7° (c = 2.97, chloroform); accurate mass 422.2289; $C_{23}H_{34}O_7$ requires M^+, 422,2303.

Methyl (1*S*,6*R*)-5-Hydroxy-4-oxabicyclo[4.3.0]non-2-ene-2-carboxylate (**12**).

According to the procedure used for the preparation of **5a**, compound **12** was obtained from **11** in 85% yield. As judged from ^1H nmr spectrum, the product is a mixture of two isomers (ratio, *ca.* 6:1); **12**, oil; ir (chloroform): 3660-3150, 1705, 1635 cm^{-1}; ^1H nmr (chloroform-d_1): 500 MHz δ 1.16-2.10 (6H, m, $C_7 \sim C_9$-H), 2.19-2.28 (6/7H, m, C_6-H), 2.37-2.44 (1/7H, m, C_6-H), 2.763 (6/7H, q, J = 8.0 Hz, C_1-H), 2.879 (1/7H, q, J = 7.0 Hz, C_1-H), 3.150 (1/7H, d, J = 7.0 Hz, C_5-OH), 3.728 (6/7H, d, J = 7.0 Hz, C_5-OH), 3.719 (1/7H, s, CO_2Me), 3.726 (6/7H, s, CO_2Me), 4.825 (6/7H, t, J = 7.0 Hz, C_5-H), 5.320 (1/7H, dd, J = 7.0, 4.0 Hz, C_5-H), 7.419 (1/7H, br s, C_3-H), 7.465 (6/7H, br s, C_3-H). $[\alpha]_D^{19}$ -18.5° (c = 2.10, chloroform); accurate mass 198.0898; $C_{10}H_{14}O_4$ requires M^+, 198.0891.

Anal. Calcd. for $C_{10}H_{14}O_4$: C, 60.59; H, 7.12. Found: C, 60.72; H, 7.21.

(1*R*,2*R*,2′*S*,4*R*,5′*R*,7*S*,8*S*,10*R*)- and (1*R*,2*R*,2′*S*,4*R*,5′*R*,7*S*,8*S*,10*S*)-7-Diacetoxymethyl-10-*t*-butyldimethylsiloxy-6-oxo-3,5-dioxatricyclo[6.3.0.$0^{2,7}$]undecane-4-spiro(2′-isopropyl-5′-methyl)cyclohexanes (**13**-*exo* and **13**-*endo*).

After bubbling argon for 5 minutes, a solution of **9** (837 mg, 2.36 mmoles) and 4-*t*-butyldimethylsiloxycyclopent-1-ene (3.97 g, 20 mmoles) in a mixture of hexane-ethyl acetate (3:1, 90 ml) was irradiated for 24 hours. The residue obtained after evaporation of the solvent (at this stage, the ratio of the two isomers was determined as 15:2 by hplc) was subjected to column chromatography (silica gel, 200 g). Elution with hexane-ethyl acetate (5:1) gave 642 mg (52%) of **13**-*exo*. Further elution with the same solvent gave 93 mg (11%) of **13**-*endo*.

Compound **13**-*exo* had mp 121-123° (needles from pentane); ir (chloroform): 1781, 1726 cm^{-1}; ^1H nmr (chloroform-d_1): 500 MHz δ 0.018, 0.033 (each 3H, s, $SiMe_2$), 0.838 (9H, s, *t*-butyl), 0.915, 0.940, 0.959 (each 3H, d, J = 7.0 Hz, CH*Me*$_2$, C_5-Me), 1.230 (1H, d, J = 13.0 Hz, axial-C_6-H), 2.080, 2.158 (each 3H, s, 2 x AcO), 2.575 (1H, ddd, J = 14.0, 3.0, 2.0 Hz, equatorial-C_6-H), 4.390-4.430 (1H, m, C_{10}-H), 4.550 (1H, dd, J = 6.0, 4.0 Hz, C_2-H), 7.249 (1H, s, C*H*$(OAc)_2$); $[\alpha]_D^{24}$ +0.4° (*c*=2.10, chloroform).

Anal. Calcd. for $C_{29}H_{48}O_8Si$: C, 63.01; H, 8.76. Found: C, 62.88; H, 8.80.

Compound **13**-*endo* was a colorless oil; ir (chloroform): 1780, 1725 cm^{-1}; ^1H nmr (chloroform-d_1): 500 MHz δ 0.028, 0.030 (each 3H, s, $SiMe_2$), 0.885 (9H, s, *t*-butyl), 0.970, 1.010, 1.040 (each 3H, d, J = 7.0 Hz, CH*Me*$_2$, C_5-Me), 1.288 (1H, t, J = 13.0 Hz, axial-C_6-H), 2.090, 2.185 (each 3H, s, 2 x AcO), 2.398-2.473 (1H, m, -C*H*Me_2), 2.648 (1H, ddd, J = 14.0, 4.0, 2.0 Hz, equatorial-C_6-H), 4.035-4.118 (1H, m, C_{10}-H), 4.639 (1H, dd, J = 6.0, 3.5 Hz, C_2-H), 7.250 (1H, s, C*H*$(OAc)_2$); $[\alpha]_D^{23}$ +3.8° (c = 1.72, chloroform). None of the several high-resolution mass determinations performed was satisfactory, probably due to facile fragmentations.

Methyl (1*S*,6*R*,8*S*)-8-Hydroxy-5-methoxy-4-oxabicyclo[4.3.0]non-2-ene-2-carboxylate (**14**).

According to the procedure used for the preparation of **7**, compound **14** was obtained from **13**-*exo* in 82% yield. As judged from ^1H nmr spectrum, the product was a mixture (ratio, *ca.* 2:1) of two isomers.

Compound **14** was a colorless oil; ir (chloroform): 3650-3150, 1703, 1635 cm^{-1}; ^1H nmr (chloroform-d_1): 500 MHz δ 1.512-2.275 (5H, m, C_7- and C_9-H, C_8-OH), 2.400 (2/3H, dq, J = 8.0, 6.5 Hz, C_6-H), 2.545-2.613 (1/3H, m, C_6-H), 3.055 (1/3H, br q, J = 8.0 Hz, C_1-H), 3.140 (2/3H, br q, J = 8.0 Hz, C_1-H), 3.423 (1H, s, C_5-OMe), 3.529 (2H, s, C_5-OMe), 3.725 (3H, s, CO_2Me), 4,375 (2/3H, br t, J = 5.0 Hz, C_8-H), 4.429 (1/3H, br t, J = 5.0 Hz, C_8-H), 4.443 (2/3H, d, J = 6.5 Hz, C_5-Hβ), 4.865 (1/3H, d, J = 3.5 Hz, C_5-Hα), 7.425

(1/3H, d, J = 1.0 Hz, C_3-H), 7.474 (2/3H, br s, C_3-H); $[\alpha]_D^{23}$ -0.9° (c = 2.11, chloroform); accurate mass 228.1044; $C_{11}H_{16}O_5$ requires M⁺, 228.0997.

Methyl (1*S*,5*S*,6*R*)- and -(1*S*,5*R*,6*R*)-5-Methoxy-8-oxo-4-oxabicyclo[4.3.0]non-2-ene-2-carboxylate (**15**-α and **15**-β).

According to the procedure for the preparation of **8**-α-and **8**-β, these two compounds were prepared in 60% (for **15**-α) and 36% yields (for **15**-β), respectively.

Compound **15**-β had mp 57-58° (needles from pentane-ether); ir (chloroform): 1745, 1705, 1635 cm^{-1}; ^1H nmr (chloroform-d_1): 500 MHz δ 2.225 (1H, ddd, J = 18.0, 7.0, 1.0 Hz, C_7-H_a), 2.342 (1H, ddd, J = 19.0, 6.0 1.0 Hz, C_9-Hα), 2.440 (1H, br dd, J = 18.0, 8.0 Hz, C_7-Hβ), 2.582-2.645 (1H, m, C_6-H), 2.680 (1H, ddd, J = 19.0, 8.0, 1.0 Hz, C_9-Hβ), 3.268 (1H, br q, J = 7.0 Hz, C_1-H), 3.538 (3H, s, C_5-OMe), 3.725 (3H, s, CO_2Me), 4.765 (1H, d, J = 5.0 Hz, C_5-H), 7.512 (1H, d, J = 1.0 Hz, C_3-H); $[\alpha]_D^{22}$ -99.6° (c = 2.00, chloroform).

Anal. Calcd. for $C_{11}H_{14}O_5$: C, 58.40; H, 6.24. Found: C, 58.30; H, 6.23.

Compound **15**-α was an oil; ir (chloroform): 1748, 1705, 1640 cm^{-1}; ^1H nmr (chloroform-d_1): 500 MHz δ 2.283 (1H, ddd, J = 18.5, 10.0, 1.5 Hz, C_9-Hα), 2.310 (1H, br d, J = 18.5 Hz, C_7-Hα), 2.423 (1H, ddd, J = 18.5, 8.5, 1.0 Hz, C_7-Hβ), 2.594 (1H, br dd, J = 18.5, 10.0 Hz, C_9-Hβ), 2.652-2.702 (1H, m, C_6-H), 3.150 (1H, br q, J = 10.0 Hz, C_1-H), 3.405 (3H, s, C_5-OMe), 3.751 (3H, s, CO_2Me), 4.985 (1H, d, J = 3.0 Hz, C_5-H), 7.490 (1H, d, J = 1.0 Hz, C_3-H); $[\alpha]_D^{21}$ +218.9° (c = 2.65, chloroform); accurate mass 226.0844; $C_{11}H_{14}O_5$ requires M⁺, 226.0840.

Anal. Calcd. for $C_{11}H_{14}O_5$: C, 58.40; H, 6.22. Found: C, 58.51; H, 6.51.

(1*S*,4*R*,6*S*,7*R*)-8,10-Dimethoxy-3,9-dioxo-2-oxatricyclo[4.4.0.-$1^{4,7}$]undecane (**16**).

p-Toluenesulfonic acid (25 mg, 0.13 mmole) and one drop of water was added to a solution of **13**-*endo* (146 mg, 0.26 mmole) in tetrahedrofuran (5 ml) at room temperature and the whole was stirred at room temperature for 2 days. After drying over sodium sulfate the solvent was evaporated under reduced pressure. The ether solution of the residue was methylated by the addition of an excess of diazomethane. The residue obtained after evaporation of ether was added IR-120B resin (1 g) and methanol (10 ml) and the mixture was stirred for 2 days. Separation of the product by ptlc (hexane-ether, 1:5) gave 20 mg (34%) of **16**.

Compound **16** was an oil; ir (chloroform): 1735 cm^{-1}; ^1H nmr (chloroform-d_1): 500 MHz δ 1.773 (1H, dt, J = 13.0, 4.0 Hz, C_5-Hα), 2.031 (1H, ddd, J = 16.0, 12.0, 6.0 Hz, C_{11}-Hβ), 2.058 (1H, dd, J = 13.0, 3.0 Hz, C_5-Hβ), 2.235 (1H, ddd, J = 16.0, 7.0, 2.0 Hz, C_{11}-Hα), 2.300-2.365 (1H, m, C_7-H), 2.730 (1H, dt, J = 6.0, 1.5 Hz, C_1-H), 2.754 (1H, br q, J = 5.0 Hz, C_6-H), 3.474 (3H, s, C_8-OMe), 3.508 (3H, s, C_{10}-OMe), 4.798-4.828 (1H, m, C_4-H), 4.964 (1H, d, J = 3.0 Hz, C_8-Hz, C_8-H), 5.269 (1H, br s, C_{10}-H); $[\alpha]_D^{24}$ +76.5° (c = 2.11, chloroform); accurate mass 227.0909; $C_{11}H_{16}O_5$ requires M⁺-1, 227.0919.

Anal. Calcd. for $C_{11}H_{16}O_5$: C, 57.88; H, 7.07. Found: C, 58.51; H, 7.25.

t-Butyl 2-Acetyl-ω-alkenoate (**18**).

General Procedure.

To a mixture of dimethylformamide (10 ml) and sodium hydride (12 mmoles), *t*-butyl acetoacetate (10 mmole) was added dropwise over 15 minutes under ice-cooling. After the addition had completed, alkenyl bromide (10 mmoles) was added to the mixture and the whole was warmed at 60° for *ca.* 17 hours. After addition of water (20 ml), the mixture was acidified with 10% hydrochloric acid and the product was extracted by ether. The ether layer was washed with water, dried over magnesium sulphate, and concentrated to give **18**.

t-Butyl 2-Acetyl-5-hexenoate (**18a**).

This compound had bp 68°/2 torr (62%); ir (chloroform): 1735, 1710, 1641, 1621 cm^{-1}; ^1H nmr (chloroform-d_1): δ 1.43 (9H, s, *t*-Bu), 1.70-2.20 (4H, m, C_3-, C_4-H), 2.20 (3H, s, Ac), 3.35 (1H, t, J = 6.0 Hz, C_2-H), 4.80-5.25 (2H, m, C_6-H), 5.35-6.15 (1H, m, C_5-H); accurate mass, 212.1411; $C_{12}H_{20}O_3$ requires M⁺, 212.1411.

t-Butyl 2-Acetyl-6-heptenoate (**18b**).

This compound had bp 82°/0.1 torr (72%); ir (chloroform): 1715, 1712, 1641, 1621 cm^{-1}; ^1H nmr (chloroform-d_1): δ 1.39 (9H, s, *t*-Bu), 1.39-2.20 (6H, m, $C_3 \sim C_5$-H), 2.20 (3H, s, Ac), 3.24 (1H, t, J = 6.0 Hz, C_2-H), 4.70-5.15 (2H, m, C_7-H), 5.40-5.99 (1H, m, C_6-H).

Anal. Calcd. for $C_{13}H_{22}O_3$: C, 68.99; H, 9.80. Found: C, 68.90; H, 10.00.

t-Butyl 2-Acetyl-7-octenoate (**18c**).

This compound had bp 91°/0.1 torr (68%); ir (chloroform): 1725, 1712, 1640, 1620 cm^{-1}; ^1H nmr (chloroform-d_1): δ 1.50 (9H, s, *t*-Bu), 1.70-2.20 (8H, m, $C_3 \sim C_6$-H), 2.20 (3H, s, Ac), 3.30 (1H, t, J = 6.0 Hz, C_2-H), 4.77-5.20 (2H, m, C_8-H), 5.33-6.20 (1H, m, C_7-H); accurate mass 240.1720; $C_{14}H_{24}O_3$ requires M⁺, 240.1724.

3-Alkenyl-2-methyl-4-oxo-1,5-dioxaspiro[5.5]undec-2-ene (**19**).

General Procedure.

To a solution of ester **18** (10 mmoles) and cyclohexanone (2.94 g, 30 mmoles) in acetic anhydride (5.10 g, 50 mmoles) was added concentrated sulfuric acid (980 mg, 10 mmoles) under stirring at below -10°. After 10 minutes, the ice bath was removed and the whole was kept standing for 4 hours at room temperature. After the reaction, the whole was poured into ice-water and stirred for 1 hour. The product was extracted with ether. The organic layer was washed with water, dried over magnesium sulphate, and evaporated (note: final evaporation was carried out under 1 torr in order to remove cyclohexanone). The residue obtained was chromatographed [silica gel, hexane-ethyl acetate (20:1)] to give **19**.

3-(3-Butenyl)-2-methyl-4-oxo-1,5-dioxaspiro[5.5]undec-2-ene (**19a**).

This compound was a colorless oil (39%); ir (chloroform): 1710, 1641 cm^{-1}; ^1H nmr (chloroform-d_1): δ 1.20-2.70 [14H, m, cyclohexyl, CH_2=CH-(CH_2)$_2$], 1.97 (3H, s, C_2-Me), 4.77-5.22 (2H, m, CH=CH_2), 5.45-6.20 (1H, m, C*H*=CH_2); accurate mass 236.1425; $C_{14}H_{20}O_3$ requires M⁺, 236.1411.

2-Methyl-4-oxo-3-(4-pentenyl)-1,5-dioxaspiro[5.5]undec-2-ene (**19b**).

This compound was a colorless oil (39%); ir (chloroform): 1718, 1645 cm^{-1}; ^1H nmr (chloroform-d_1): δ 1.20-2.60 [14H, m, cyclohexyl, CH_2=CH-(CH_2)$_2$], 1.97 (3H, s, C_2-Me), 4.77-5.25 (2H, m, CH=CH_2), 5.30-6.20 (1H, m, C*H*=CH_2); accurate mass 250.1544; $C_{15}H_{22}O_3$ requires M⁺, 250.1568.

3-(5-Hexenyl)-2-methyl-4-oxo-1,5-dioxaspiro[5.5]undec-2-ene (**19c**).

This compound was a colorless oil (45%); ir (chloroform): 1715, 1641 cm^{-1}; ^1H nmr (chloroform-d_1): δ 1.20-2.65 [14H, m, cyclohexyl, CH_2=CH-(CH_2)$_2$], 2.00 (3H, s, C_2-Me), 4.75-5.29 (2H, m,

CH=C*H*$_2$), 5.29-6.22 (1H, m, C*H*=CH$_2$); accurate mass 264.1748; $C_{16}H_{24}O_3$ requires M$^+$, 264.1724.

(6*S*,7*S*,10*R*)- and (6*R*,7*S*,10*R*)-3-(3-Butenyl)-7-isopropyl-2,10-dimethyl-4-oxo-1,5-dioxaspiro[5.5]undec-2-ene (*S*- and *R*-**24a**).

To a solution of ester **18** (2.12 g, 10 mmoles) and *l*-menthone (4.63 g, 30 mmoles) in acetic anhydride (5.10 g, 50 mmoles) was added concentrated sulfuric acid (0.98 g, 10 mmoles) under stirring. During this process, the internal temperature should be kept below -10° by cooling with external ice-salt bath. After 10 minutes, the bath was taken off and the whole was kept standing for 4 hours at room temperature. The whole was poured into ice-water and stirred for 1 hour and extracted with ether. The ether layer was washed with water, dried over magnesium sulfate, and evaporated [note: the *l*-menthone should also be removed off (*ca.* 60°/0.1 torr)]. The residue obtained was separated by silica gel column chromatography (30 g). Elution with hexane-ethyl acetate (20:1) gave 542 mg (19%) of a mixture of *S*- and *R*-**24a**. The ratio of two isomers was determined by hplc (hexane-tetrahydrofuran, 100:1) as *ca.* 10:1 as *S*-**24a** being the major isomer. Separation of the mixture by Robar column B (hexane-ether, 100:1) gave at first 321 mg (11%) of *S*-**24a** and then 46 mg (2%) of *R*-**24a**.

Compound *S*-**24a**. This compound was an oil; ir (chloroform): 1710, 1641 cm^{-1}; ^{1}H nmr (chloroform-d$_1$): 500 MHz δ 0.870, 0.909, 0.954 (each 3H, d, J = 7.5 Hz, isopropyl-Me, C$_{10}$-Me), 0.956 (1H, t, J = 13.0 Hz, axial-C$_{11}$-H), 1.455 (1H, dt, J = 12.5, 4.0 Hz, C$_7$-H), 1.998 (3H, s, C$_2$-Me), 2.18-2.30 [1H, m, C$_7$-C*H*(CH$_2$)$_2$], 2.642 (1H, ddd, J = 12.5, 4.0, 2.5 Hz, equatorial-C$_{11}$-H), 4.982 (1H, dd, J = 10.0, 2.0 Hz, CH=C*H*$_2$), 5.035 (1H, dd, J = 17.5, 2.0 Hz, CH=C*H*$_2$), 5.810 (1H, ddt, J = 17.5, 10.0, 7.0 Hz, C*H* = CH$_2$); $[\alpha]_D^{23}$ +8.07° (c = 1.0, chloroform); accurate mass, 292.2060; $C_{18}H_{28}O_3$ requires M$^+$, 292.2037.

Compound *R*-**24a** was an oil; ir (chloroform): 1710, 1645 cm^{-1}; ^{1}H nmr (chloroform-d$_1$): 500 MHz δ 0.871, 0.876, 0.938 (each 3H, d, J = 7.0 Hz, isopropyl-Me, C$_{10}$-Me), 1.044 (1H, t, J = 13.0 Hz, axial-C$_{11}$-H), 2.00 (3H, s, C$_2$-Me), 2.300-2.388 [1H, m, C$_7$-C*H*(CH$_2$)$_2$], 2.650 (1H, ddd, J = 14.0, 4.0, 2.5 Hz, equatorial-C$_{11}$-H), 4.986 (1H, dd, J = 10.0, 2.0 Hz, CH=C*H*$_2$), 5.040 (1H, dd, J = 17.5, 2.0 Hz, CH=C*H*$_2$), 5.800 (1H, ddt, J = 17.5, 10.0, 7.0 Hz, C*H*=CH$_2$); $[\alpha]_D^{22}$ -36.4° (c = 2.01, chloroform); accurate mass 292.2041; $C_{18}H_{28}O_3$ requires M$^+$, 292.2037.

(6*S*,7*S*,10*R*)- and (6*R*,7*S*,10*R*)-7-Isopropyl-2,10-dimethyl-4-oxo-3-(3-pentenyl)-1,5-dioxaspiro[5.5]undec-2-ene (*S*- and *R*-**24b**).

a) To a solution of sodium hydroxide (0.48 g, 12 mmoles) in water (100 ml) was added ethyl 2-acetyl-6-heptenoate (2.54 g, 10 mmoles) and the whole was stirred at room temperature for 5 hours. After acidification by the addition of 10% hydrochloric acid, the product was extracted with ether. Evaporation of ether after short drying with magnesium sulfate gave crude 2-acetyl-6-heptenoic acid as an oil. The oil was dissolved in acetic anhydride (5.10 g, 50 mmoles) containing *l*-menthone (4.63 g, 30 mmoles), and to this mixture concentrated sulfuric acid (980 mg, 10 mmoles) was added slowly under ice-salt cooling. The whole was stored for 2 days at *ca.* -5° and then poured into ice-water. After the whole was stirred for 1 hour, the product was extracted with ether. The organic layer was evaporated under reduced pressure (note: in order to remove *l*-menthone, evaporation should be carried out at 60° under 0.1 torr). The residue obtained was chromatographed over silica gel (30 g). Elution with hexane-ethyl acetate (20:1) gave 0.78 g (26%) of **38** as a mixture of two isomers. At this stage, ratio (*S*/*R* = 3.3) of two isomers was determined by hplc (hexane-tetrahydrofuran, 100:1). Two isomers were separated by Robar column B with hexane-ether (100:1) to give at first *S*-**24b** and then *R*-**24b**.

b) To a solution of ester **18b** (361 mg, 1.6 mmoles) and *l*-menthone (768 mg, 4.8 mmoles) in acetic anhydride (847 mg, 8.0 mmoles) was added concentrated sulfuric acid (157 mg, 1.6 mmoles) under vigorous stirring. The whole procedure should be carried out below -10°. After 10 minutes, the ice-salt bath was removed and the whole was kept standing at room temperature for 7 hours. After poured into ice-water and stirred for 1 hour, the product was extracted with ether. The organic layer was washed with water, dried over magnesium sulfate, and evaporated (in order to remove *l*-menthone, final evaporation should be carried out at 60° under 0.1 torr). The residue thus obtained was chromatographed over silica gel (30 g). Elution with hexane-ethyl acetate (20:1) gave 201 mg (21%) of **24b** as a mixture of two isomers.

Compound *S*-**24b** was an oil; ir (chloroform): 1715, 1641 cm^{-1}; ^{1}H nmr (chloroform-d$_1$): 500 MHz δ 0.875 (3H, d, J = 7.0 Hz, C$_{10}$-Me), 0.910, 0.956 (each 3H, d, J = 7.5 Hz, isopropyl-Me), 0.980 (1H, t, J = 12.5 Hz, axial-C$_{11}$-H), 1.460 (1H, dt, J = 12.5, 4.0 Hz, C$_7$-H), 1.995 (3H, s, C$_2$-Me), 2.21-2.28 (1H, m, C$_7$-C*H*Me$_2$), 2.580 (1H, ddd, J = 12.5, 4.0, 2.5 Hz, equatorial-C$_{11}$-H), 4.970 (1H, dd, J = 10.0, 2.5 Hz, CH=C*H*$_2$), 5.028 (1H, dd, J = 17.5, 2.5 Hz, CH=C*H*$_2$), 5.828 (1H, ddt, J = 17.5, 10.0, 7.5 Hz, C*H*=CH$_2$); $[\alpha]_D^{25}$ +19.4° (c = 2.07, chloroform); accurate mass 306.2184; $C_{19}H_{30}O_3$ requires M$^+$, 306.2193.

Compound *R*-**24b**: was an oil; ir (chloroform): 1705, 1645 cm^{-1}; ^{1}H nmr (chloroform-d$_1$): 500 MHz δ 0.875, 0.890 (each 3H, d, J = 5.0 Hz, isopropyl-Me), 0.940 (3H, d, J = 7.5 Hz, C$_{10}$-Me), 1.070 (1H, t, J = 13.0 Hz, axial-C$_{11}$-H), 1.35-1.57 (1H, m, C$_7$-H), 1.998 (3H, s, C$_2$-Me), 2.28-2.38 (1H, m, C$_7$-C*H*Me$_2$), 2.558 (1H, ddd, J = 12.5, 4.0, 2.5 Hz, equatorial-C$_{11}$-H), 4.972 (1H, dd, J = 10.0, 2.0 Hz, CH=C*H*$_2$), 5.030 (1H, dd, J = 17.5, 2.5 Hz, CH=C*H*$_2$), 5.825 (1H, ddt, J = 17.5, 10.0, 7.5 Hz, C*H*=CH$_2$); $[\alpha]_D^{26}$ -48.4° (c = 2.00, chloroform); accurate mass 306.2187; $C_{19}H_{30}O_3$ requires M$^+$, 306.2193.

(6*S*,7*S*,10*R*)- and (6*R*,7*S*,10*R*)-3-(5-Hexenyl)-7-isopropyl-2,10-dimethyl-4-oxo-1,5-dioxaspiro[5.5]undec-2-ene (*S*- and *R*-**24c**).

Concentrated sulfuric acid (0.98 g, 10 mmoles) was added to a solution of ester **18c** (4.08 g, 17 mmoles) and *l*-menthone (7.87 g, 51 mmoles) in acetic anhydride (8.67 g, 85 mmoles) under stirring. The whole operation should be carried out in an ice-salt bath to keep the reaction temperature below -10°. After 10 minutes, the bath was removed and the whole was kept standing 4 hours at room temperature. The mixture was poured into ice-water and stirred for 1 hour. The product was extracted with ether and the organic layer was washed with water, dried and evaporated (finally, 60°/0.1 torr was necessary to remove *l*-menthone). The residue was chromatographed on silica gel (50 g). Elution with hexane-ethyl acetate (20:1) gave 2.25 g (41%) of **24c** as a mixture of two isomers. At this stage, ratio of *S*-**24c**/*R*-**24c** was determined as 31/5 by hplc (hexane-ether, 100:1). Two isomers were separated by Robar column C with hexane-ether (100:1) to give at first 1.036 g (19%) of *S*-**24c** and then 370 mg (7%) of *R*-**24c**.

Compound *S*-**24c** was a colorless oil; ir (chloroform): 1715, 1642 cm^{-1}; ^{1}H nmr (chloroform-d$_1$): 500 MHz δ 0.871, 0.953 (each 3H, d, J = 7.0 Hz, isopropyl-Me), 0.908 (3H, d, J = 7.5 Hz,

C_{10}-Me), 0.975 (1H, t, J = 12.5 Hz, axial-C_{11}-H), 2.123 (3H, s, C_2-Me), 2.21-2.28 (1H, m, C_7-C*H*Me$_2$), 2.580 (1H, ddd, J = 12.5, 4.0, 2.5 Hz, equatorial-C_{11}-H), 4.92-5.04 (2H, m, CH=C*H*$_2$), 5.808 (1H, ddt, J = 16.0, 10.0, 7.0 Hz, C*H*=CH$_2$); $[\alpha]_D^{30}$ +14.3° (c = 3.69, chloroform); accurate mass 320.2368; $C_{20}H_{32}O_3$ requires M$^+$, 320.2350.

Compound *R*-**24c** was a colorless oil; ir (chloroform): 1709, 1643 cm^{-1}; ^{1}H nmr (chloroform-d_1): δ 0.874, 0.884 (each 3H, d, J = 7.0 Hz, isopropyl-Me), 0.938 (3H, d, J = 7.5 Hz, C_{10}-Me), 1.062 (1H, t, J = 13.0 Hz, axial-C_{11}-H), 1.985 (3H, s, C_2-Me), 2.28-2.38 (1H, m, C_7-C*H*Me$_2$), 2.585 (1H, ddd, J = 14.0, 4.0, 2.5 Hz, equatorial-C_{11}-H), 4.915-5.035 (2H, m, CH=C*H*$_2$), 5.809 (1H, ddt, J = 16.0, 10.0 7.0 Hz, C*H*=CH$_2$); $[\alpha]_D^{30}$ -33.0° (c = 3.49, chloroform); accurate mass 320.2379; $C_{20}H_{32}O_3$ requires M$^+$, 320.2350.

6-Methyl-2-oxo-3,5-dioxatricyclo[4.3.0.1^{1,7}]decane-4-spirocyclohexane (**20**).

A solution of **19a** (100 mg, 0.42 mmole) in acetonitrile-acetone (9:1, 200 ml) was irradiated for 2.5 hours under bubbling argon. Evaporation followed by chromatography over silica gel (18 g) afforded upon elution with hexane-ethyl acetate (10:1) 66 mg (66%) of **20**.

Compound **20** had mp 44-45° (prisms from pentane); ir (chloroform): 1733 cm^{-1}; ^{1}H nmr (chloroform-d_1): δ 1.30 (3H, s, C_6-Me), 1.3-2.9 (11H, m); accurate mass 236.1433; $C_{14}H_{20}O_3$ requires M$^+$, 236.1411.

Anal. Calcd. for $C_{14}H_{20}O_3$: C, 71.16; H, 8.53. Found: C, 71.23; H, 8.69.

3-Methyl-7-oxo-4,6-dioxatricyclo[6.3.0.0^{3,8}]undecane-5-spirocyclohexane (**21b**).

Compound **19b** (100 mg) was irradiated in acetonitrile-acetone in the same manner as above to give 87 mg (87%) of **21b**.

Compound **21b** had mp 83-84° (prisms from pentane); ir (chloroform): 1715 cm^{-1}; ^{1}H nmr (chloroform-d_1): δ 1.3-2.7 (18H, m), 1.47 (3H, s, C_3-Me), 2.77-3.33 (1H, m, C_1-H); accurate mass 250.1591; $C_{15}H_{22}O_3$ requires M$^+$, 250.1568.

Anal. Calcd. for $C_{15}H_{22}O_3$: C, 71.97; H, 8.86. Found: C, 72.20; H, 8.65.

3-Methyl-7-oxo-4,6-dioxatricyclo[6.3.0.0^{3,8}]dodecane-5-spirocyclohexane (**21c**).

Compound **19c** (80 mg, 0.30 mmole) was irradiated (2.5 hours) in acetonitrile-acetone (9:1, 180 ml) under the same condition as above to give 56 mg (70%) of **21c**.

Compound **21c** had mp 72-73° (prisms from pentane); ir (chloroform): 1720 cm^{-1}; ^{1}H nmr (chloroform-d_1): δ 0.9-2.3 (20H, m), 1.49 (3H, s, C_3-H), 2.53-3.07 (1H, m, C_1-H); accurate mass 264.1767; $C_{16}H_{24}O_3$ requires M$^+$, 264.1724.

Anal. Calcd. for $C_{16}H_{24}O_3$: C, 72.69; H, 9.15. Found: C, 72.70; H, 9.00.

(1*S*,2′*S*,3*S*,5*S*,5′*R*,8*R*) and (1*R*,2′*S*,3*R*,5*S*,5′*R*,8*S*)-3-Methyl-7-oxo-4,6-dioxatricyclo[6.3.0.0^{3,8}]undecane-5-spiro(2′-isopropyl-5′-methyl)cyclohexane (**27** and **28**).

Compound *S*-**24b** (100 mg, 0.33 mmole) was irradiated (40 minutes) in acetonitrile-acetone (9:1, 200 ml) under the same condition as above to give, after separation by column chromatography over silica gel (5 g) with hexane-ethyl acetate (10:1) as the eluent, a mixture (*ca.* 1:1 ratio) of **27** and **28** in a quantitative yield. Separation of the mixture by column chromatography [Robar column B, hexane-ethyl acetate (50:1)] gave at first 43 mg (43%) of **28** and then **39** mg (39%) of **27**.

Compound **27** had mp 72-73° (prisms from pentane); ir (chloroform): 1715 cm^{-1}; ^{1}H nmr (chloroform-d_1): 500 MHz δ 0.814, 0.919 (each 3H, d, J = 7.0 Hz, isopropyl-Me), 0.902 (3H, d, J = 7.5 Hz, $C_{5'}$-Me), 1.271 (3H, s, C_3-Me), 1.435 (1H, t, J = 13.0 Hz, axial-$C_{6'}$-H), 2.190-2.288 (1H, m, $C_{2'}$-C*H*Me$_2$), 2.525 (1H, ddd, J = 18.0, 4.0, 2.0 Hz, equatorial-$C_{6'}$-H), 3.040 (1H, dt, J = 10.0, 6.0 Hz, C_1-H); $[\alpha]_D^{28}$ -29.2° (c = 2.00, chloroform); accurate mass 306.2200; $C_{19}H_{30}O_3$ requires M$^+$, 306.2193.

Anal. Calcd. for $C_{19}H_{30}O_3$: C, 74.47; H, 9.87. Found: C, 74.70; H, 10.15.

Compound **28** was an oil; ir (chloroform): 1715 cm^{-1}; ^{1}H nmr (chloroform-d_1): 500 MHz δ 0.875 (3H, d, J = 6.8 Hz, $C_{5'}$-Me), 0.918, 0.958 (each 3H, d, J = 7.0 Hz, isopropyl-Me), 1.245 (1H, t, J = 17.5 Hz, axial-$C_{6'}$-H), 1.405 (3H, s, C_3-Me), 2.41-2.50 (1H, m, $C_{2'}$-C*H*Me$_2$), 2.975 (1H, dt, J = 10.0, 4.0 Hz, C_1-H); $[\alpha]_D^{28}$ -12.1° (c = 2.00, chloroform); accurate mass 306.2202; $C_{19}H_{30}O_3$ requires M$^+$, 306.2193.

Anal. Calcd. for $C_{19}H_{30}O_3$: C, 74.47; H, 9.87. Found: C, 74.65; H, 9.95.

(1*S*,2′*S*,3*S*,5*S*,5′*R*,8*R*)-3-Methyl-7-oxo-4,6-dioxatricyclo[6.4.0.0^{3,8}]-dodecane-5-spiro-(2′-isopropyl-5′-methyl)cyclohexane (**25**).

Compound *S*-**24c** (100 mg, 0.31 mmole) was irradiated in acetonitrile-acetone (9:1, 200 ml) in the same manner as above to give 98 mg (98%) of **25**.

Compound **25** had mp 107～108° (prisms from pentane); ir (chloroform): 1720 cm^{-1}; ^{1}H nmr (chloroform-d_1): 500 MHz δ 0.870 (3H, d, J = 6.7 Hz, $C_{5'}$-Me), 0.899, 0.950 (each 3H, d, J = 7.3 Hz, isopropyl-Me), 1.230 (1H, t, J = 12.5 Hz, axial-$C_{6'}$-H), 1.479 (3H, s, C_3-Me), 2.434-2.535 (1H, m, $C_{2'}$-C*H*Me$_2$); $[\alpha]_D^{29}$ -12.4° (c = 3.36, chloroform); accurate mass 320.2354; $C_{20}H_{32}O_3$ requires M$^+$, 320.2350.

Anal. Calcd. for $C_{20}H_{32}O_3$: C, 74.96; H, 10.06. Found: C, 75.12; H, 9.87.

Methyl (*E*)- and (*Z*)-3-Acetylcyclopentanecarboxylate (*E*-**22** and *Z*-**22**).

Adduct **20** (59 mg, 0.25 mmole) was refluxed in water (2 ml) for 5 hours. After the reaction, the product was extracted with ether. The crude acid thus obtained was then treated with an excess of diazomethane. Separation of the product by ptlc [developed three times with hexane-ethyl acetate (10:1)] gave 17 mg (34%) of the less polar and 15 mg (30%) of the more polar esters. At present, we could not determine which was the *E*- and the *Z*-isomers. The less polar ester: oil; ir (chloroform): 1730, 1715 cm^{-1}; ^{1}H nmr (chloroform-d_1): δ 1.7-2.5 (6H, m, $C_{2'}$-, $C_{4'}$-, C_5-H), 2.15 (3H, s, Ac), 2.6-3.4 (2H, m, $C_{1'}$-, C_3-H), 3.67 (3H, s, CO_2Me); accurate mass 170.0942; $C_9H_{14}O_3$ requires M$^+$, 170.0942.

The more polar ester was an oil; ir (chloroform): 1720, 1715 cm^{-1}; ^{1}H nmr (chloroform-d_1): δ 1.7-2.3 (6H, m, $C_{2'}$-, $C_{4'}$-, C_5-H), 2.17 (3H, s, Ac), 2.50-3.63 (2H, m, $C_{1'}$, C_3-H), 3.67 (3H, s, CO_2Me); accurate mass 170.0948; $C_9H_{14}O_3$ requires M$^+$, 170.0942.

Methyl (*E*)- and (*Z*)-2-Acetonylcyclopentanecarboxylate (**23b**).

By the same procedure as above, 15 mg (32%) of the less polar ester and 12 mg (26%) of the more polar ester were obtained from adduct **21b** (63 mg, 0.25 mmole). Though the less polar ester (the major isomer) is expected to be the *E*-isomer, final

determination has not been done yet.

The less polar ester was an oil; ir (chloroform): 1722 cm^{-1}; ^1H nmr (chloroform-d_1): δ 1.15-2.20 (6H, m, $C_3 \sim C_5$-H), 2.12 (3H, s, Ac), 2.35-3.27 (4H, m, C_1-H, C_2-H, C_2-CH_2), 3.65 (3H, s, CO_2Me); accurate mass 184.1057; $C_{10}H_{16}O_3$ requires M^+, 184.1099.

The more polar ester was an oil; ir (chloroform): 1722 cm^{-1}; ^1H nmr (chloroform-d_1): δ 1.1-3.1 (10H, m), 2.13 (3H, s, Ac), 3.69 (3H, s, CO_2Me); accurate mass 184.1100; $C_{10}H_{16}O_3$ requires M^+, 184.1099.

Methyl (*E*)- and (*Z*)-(2*S*)-2-Acetonylcyclopentanecarboxylate (2*S*-**29**).

By the same procedure as in the racemic series, 15 mg (35%) of the less polar ester and 12 mg (28%) of the more polar ester were obtained from adduct **27** (70 mg, 0.25 mmole).

The less polar ester was an oil; ir (chloroform): 1722 cm^{-1}; ^1H nmr (chloroform-d_1): δ 1.2-2.2 (6H, m, C_3- ~ C_5-H), 2.19 (3H, s, Ac), 2.3-3.15 (4H, m, C_1- and C_2-H, C_2-CH_2), 3.65 (3H, s, CO_2Me); $[\alpha]_D^{23}$ -14.1° (c = 0.71, chloroform); accurate mass 184.1079; $C_{10}H_{16}O_3$ requires M^+, 184.1099.

The more polar ester was an oil; ir (chloroform): 1722 cm^{-1}; ^1H nmr (chloroform-d_1): δ 1.0-3.0 (10H, m), 2.13 (3H, s, Ac), 3.67 (3H, s, CO_2Me); $[\alpha]_D^{24}$ +50.0° (c = 0.66, chloroform); accurate mass 184.1086; $C_{10}H_{16}O_3$ requires M^+, 184.1099.

Methyl (*E*)- and (*Z*)-(2*R*)-2-Acetonylcyclopentanecarboxylate (2*R*-**29**).

By the same procedure as above, 6 mg (35%) of the less polar ester and 7 mg (38%) of the morepolar ester were obtained from adduct **28** (30 mg, 0.10 mmole).

The less polar ester was an oil; ir (chloroform): 1722 cm^{-1}; ^1H nmr (chloroform-d_1): δ 1.2-2.4 (6H, m, C_3- - C_5-H), 2.10 (3H, s, Ac), 2.1-3.2 (4H, m, C_1- and C_2-H, C_2-CH_2), 3.60 (3H, s, CO_2Me); $[\alpha]_D^{26}$ +13.3° (c = 0.30, chloroform); accurate mass 184.1094; $C_{10}H_{16}O_3$ requires M^+, 184.1099.

The more polar ester was an oil; ir (chloroform): 1722 cm^{-1}; ^1H nmr (chloroform-d_1): δ 0.9-3.1 (10H, m), 2.10 (3H, s, Ac), 3.65 (3H, s, CO_2Me); $[\alpha]_D^{27}$ -43.2° (c = 0.19); accurate mass 184.1102; $C_{10}H_{16}O_3$ requires M^+, 184.1099.

Optically Active Methyl (*E*)- and (*Z*)-2-Acetonylcyclohexanecarboxylates (*E*-**26** and *Z*-**26**).

According to the procedure employed in the conversion of **21c** to **23c**, the adduct **25** (420 mg, 1.32 mmoles) was converted to the corresponding methyl ester **26** (243 mg, 93%) as a mixture of *E*-and *Z*-isomers. Separation of the mixture by Merck Robar column B gave 96 mg (37%) of the less polar ester and 54 mg (21%) of the more polar ester.

The less polar ester was an oil; ir (chloroform): 1725 cm^{-1}; ^1H nmr (chloroform-d_1): δ 1.15-2.00 (8H, m, $C_3 \sim C_6$-H), 2.13 (3H, s, Ac), 2.36-2.77 (4H, m, C_1-H, C_2-H, C_2-CH_2), 3.55 (3H, s, CO_2Me); $[\alpha]_D^{26}$ +23.0° (c = 1.98, chloroform); accurate mass 198.1234; $C_{11}H_{18}O_3$ requires M^+, 198.1255.

Anal. Calcd. for $C_{11}H_{18}O_3$: C, 66.64; H, 9.15. Found: C, 66.72; H, 9.20.

The more polar ester was an oil; ir (chloroform): 1725 cm^{-1}; ^1H nmr (chloroform-d_1): δ 0.8-2.6 (12H, m), 2.10 (3H, s, Ac), 3.76 (3H, s, CO_2Me); $[\alpha]_D^{26}$ -21.7° (c = 2.19, chloroform); accurate mass 198.1245; $C_{11}H_{18}O_3$ requires M^+, 198.1255.

Anal. Calcd. for $C_{11}H_{18}O_3$: C, 66.64; H, 9.15. Found: C, 66.78; H, 9.30.

Crystallographic Measurement of **5a** and **25**.

Reflection data were collected on a Rigaku AFC-5R diffractometer with graphite-monochromated CuKα radiation (λ = 1.54184 Å). The structures were solved by the direct method using the program SHELXS 86 [27] and the atomic parameters were refined by the block-diagonal least-squares method. The refinements were performed first isotropically and then anisotropically for non-hydrogen atoms. Hydrogen atoms located from difference Fourier maps were refined isotropically, but others were geometrically calculated and not included in the refinements.

Compound **5a**.

Colorless prismatic crystals were grown in pentane solution. A crystal of approximate dimensions of 0.4 x 0.1 x 0.05mm^3 was used for data collection. The crystal data are as follows: $C_{19}H_{26}O_7$, M_r = 366.411, monoclinic, space group $P2_1/c$, a = 15.226(9), b = 10.637(1), c = 12.437(5)Å, Z = 4, D_{calcd} = 1.283 g/cm^3. Intensities were measured in the θ-2θ scan mode with a scanning speed of 8°(2θ)/min. Of 2039 independent reflections with $2\theta < 105°$, 140 weak reflections below the background were considered to be zero reflections; the observational threshold value, F_{lim}, was 0.134. Corrections were made for Lorenz and polarization factors but not for absorption. The final R value was 0.087 for reflections with $|F_o| > 3\sigma|F_o|$.

Compound **25**.

Colorless prismatic crystals were grown in methanol solution. A crystal of approximate dimensions of 0.3 x 0.1 x 0.1 mm^3 was used for data collection. The crystal data are as follows: $C_{20}H_{32}O_3$.M_r = 320.472, orthorhombic, space group $P2_12_12_1$, a = 12.872 (6), b = 16.738(2), c = 8.642(3)Å; Z = 4, D_{calcd} = 1.143 g/cm^3. Intensities were measured in the θ-2θ scan mode with a scanning speed of 8° (2θ)/min. Of 1533 independent reflections with $2\theta < 120°$, 76 weak reflections below the background were considered to be zero reflections; the observational threshold value, F_{lim}, was 0.324. Corrections were made for Lorentz and polarization factors but not for absorption. The final R value was 0.040 for reflections with $|F_o| > 3\sigma|F_o|$.

Coordinates, distances and angles of single crystal structures of **5a** and **25** are available on request.

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