(VXR-200) superconducting NMR spectrometer.

General Procedure for Preparation of Alkylphosphonic Acid Dichloride. To a suspension of hydrocarbon (10.0 mmol), aluminum chloride (1.72 g, 13.0 mmol), and dry dichloromethane (25 mL) was slowly added a 2 M solution of phosphorus trichloride in dichloromethane (5.5 mL, 11.0 mmol) with stirring under nitrogen atmosphere at 0 °C (ice bath) during a period of 10 min. After the addition of phosphorus trichloride had been completed, the ice bath was removed and the reaction mixture was heated to reflux for the stipulated time (Table I) and cooled, and then a 10% aqueous solution of hydrochloric acid was slowly added. After the addition of hydrochloric acid to the reaction mixture, stirring was continued for another 0.5 h. Normal workup and extraction was carried out with dichloromethane (5 mL × 3), and the combined organic layer was dried over anhydrous magnesium sulfate; evaporation in vacuo afforded the crude products, which could be purified via column chromatography on silica gel (hexane and dichloromethane as eluents) to give the corresponding alkylphosphonic acid dichlorides.

1-Adamantylphosphonic Acid Dichloride (1). The reaction of adamantane (1.36 g, 10.0 mmol), $AlCl_3$, and PCl_3 in the ratio provided in Table I gave 1. All the spectral data were consistent with the literature values.[9]

(3,5-Dimethyladamantyl)phosphonic Acid Dichloride (2). The reaction of 1,3-dimethyladamantane (1.6 g, 10 mmol), $AlCl_3$, and PCl_3 gave 2 as colorless crystals, mp 78.5–80.2 °C. $C_{12}H_{19}POCl_2$ Calcd: C, 51.24; H, 6.77; P, 11.03. Found: C, 50.88; H, 6.52; P, 10.93.

(3-Isopropyladamantyl)phosphonic Acid Dichloride (3). The reaction of 1-isopropyladamantane (1.78 g, 10.0 mmol), $AlCl_3$, and PCl_3 gave 3 as a colorless liquid, bp 141–142 °C (1.0 mm). $C_{13}H_{21}POCl_2$ Calcd: C, 52.91; H, 7.12. Found: C, 53.12; H, 7.09.

3-Diamantylphosphonic Acid Dichloride (4). The reaction of diamantane[22] (1.88 g, 10.0 mmol), $AlCl_3$, and PCl_3 gave 4 as colorless crystals, mp 288–289 °C. $C_{14}H_{19}POCl_2$ Calcd: C, 55.11; H, 6.23; P, 10.16; Cl, 23.28. Found: C, 54.88; H, 6.40; P, 10.55; Cl, 23.52.

1-Bicyclo[2.2.2]octylphosphonic Acid Dichloride (5). The reaction of bicyclo[2.2.2]octane (1.10 g, 10.0 mol), $AlCl_3$, and PCl_3 gave 5 as a colorless liquid, bp 69–70 °C (1.0 mm). $C_8H_{13}POCl_2$ Calcd: C, 42.32; H, 5.73. Found: C, 42.55; H, 5.61.

Cyclopentylphosphonic Acid Dichloride (6). From the reaction of cyclopentane (0.7 g, 10.0 mmol), $AlCl_3$, and PCl_3 was obtained 6. All spectral data were consistent with the literature values.[23]

***tert*-Butylphosphonic Acid Dichloride (7).** The reaction of condensed isobutane (0.58 g, 10.0 mmol), $AlCl_3$, and PCl_3 in a closed vessel gave 7 as a colorless liquid, bp 45–46 °C (30 mm). $C_4H_9POCl_2$ Calcd: C, 27.63; H, 5.14; Cl, 40.57. Found: C, 27.88; H, 5.09; Cl, 40.19.

Acknowledgment. Support of this work by the National Institutes of Health is gratefully acknowledged.

(23) Christol, C.; Christol, H. *J. Chim. Phys.* **1965**, *62*(3), 246.

Difunctionalized 4-Nitroisoxazoles as Dienophiles in Diels–Alder Reactions[1]

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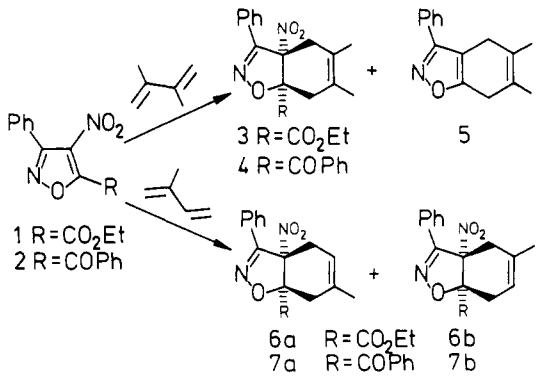
[2 + 4] Cycloadditions of the nitroisoxazoles 1 and 2 with 2,3-dimethylbuta-1,3-diene afforded the bicyclic derivatives 3 and 4 in good yields; the regio- and stereochemical pattern of the reactions of the same compounds with isoprene and cyclohexa-1,3-diene, respectively, was investigated. The structures of the new compounds were established on the basis of spectroscopic and chemical data.

A great deal of work carried out over a century[2] well established for the isoxazole ring a peculiar and versatile reactivity that appears very attractive both from a mechanistic viewpoint and for synthetic purposes. Despite that, the possibility of employing "aromatic" derivatives of this system as dienophiles remained unexplored until ethyl 4-nitro-3-phenylisoxazole-5-carboxylate (1) was found to react with 2,3-dimethylbuta-1,3-diene (DMB) in toluene at 110 °C to give the cycloadduct 3 in good yields together with a small amount of the dihydro-1,2-benzisoxazole 5[1] (Scheme I).

In an effort to expand the scope of this new [2 + 4] cycloaddition process in the isoxazole series, we now report the behavior of the corresponding nitro ketone 2, recently obtained in our laboratory,[3] with the same reagent, as well as the reactivity of compounds 1 and 2 toward isoprene and cyclohexa-1,3-diene, respectively.

Scheme I



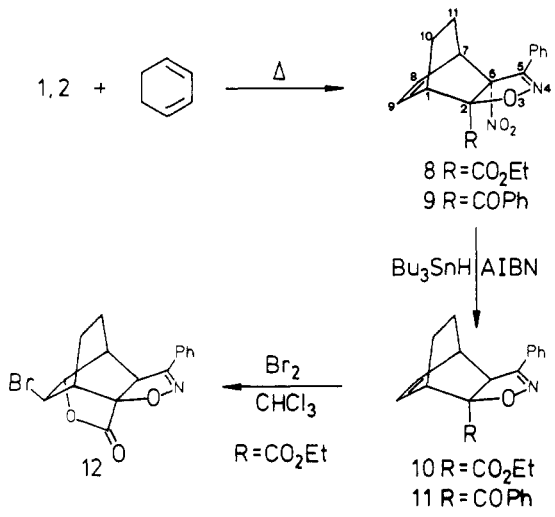
(1) For a preliminary communication on a part of this work, see: Nesi, R.; Giomi, D.; Papaleo, S.; Quartara, L. *J. Chem. Soc., Chem. Commun.* **1986**, 1536.

(2) (a) Quilico, A. In *Five- and Six-membered Compounds with Nitrogen and Oxygen*; Wiley, R. H., Ed.; Wiley-Interscience: New York, 1962; p 1. (b) Lang, S. A., Jr.; Lin, Y.-i. In *Comprehensive Heterocyclic Chemistry*; Potts, K. T., Ed.; Pergamon Press: Oxford, 1984; Vol. 6, Part 4B, p 1. (c) Lipshutz, B. H. *Chem. Rev.* **1986**, *86*, 795. (d) Torssell, K. B. G. In *Nitrile Oxides, Nitrones, and Nitronates in Organic Synthesis. New Strategies in Synthesis*; Feuer, H. Ed.; VCH Publishers: New York, 1988; p 129.

(3) Nesi, R.; Giomi, D.; Papaleo, S.; Bracci, S.; Dapporto, P. *Synthesis* **1988**, 884.

0022-3263/90/1955-1227$02.50/0

Scheme II



Results and Discussion

When **2** was allowed to react with DMB under the same conditions, the tetrahydro-1,2-benzisoxazole **4** was obtained in 60% yield; a minor amount of the bicyclic derivative **5** was again isolated from the reaction mixture by flash chromatography.

Bearing in mind that dimethyl 3-phenylisoxazole-4,5-dicarboxylate was completely inert toward DMB even under more drastic conditions,[1] the above findings demonstrate that the presence of a NO_2 group at position 4 plays a determinant role for the cycloaddition; on the other hand, the formation of compound **5** clearly indicates that the primary cycloadducts **3** and **4** partially suffer from extrusion of the electron-withdrawing groups,[4] that can be controlled by a suitable choice of the reaction times.

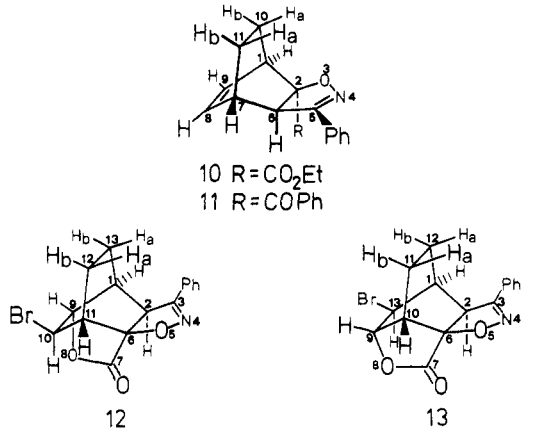
The reactivity of the nitroisoxazoles **1** and **2** with isoprene under the above standard conditions was notably lower, and the starting materials were largely recovered; however, chromatographic workup of the raw products allowed us to isolate 1:1 adducts which were identified as 5:1 mixtures of the isomers **6a** and **6b**, and **7a** and **7b**, respectively.[5]

The regiochemical control exerted by the NO_2 group of the isoxazole system was sensibly higher than that observed for similar cycloadditions both on 3-nitro-2-cyclohexen-1-one,[6] and 1-(phenylsulfonyl)-3-nitropyrrole.[7]

In order to evaluate the diastereoselectivity of these processes, we examined the behavior of the same compounds with cyclohexa-1,3-diene, for which an intermediate reactivity was observed leading exclusively to the stereoisomers **8** and **9**, respectively; the structures of these products, strongly suggested by the spectral data (see below), were confirmed by chemical evidence.

According to the method widely employed by Ono with different nitrocompounds,[8] chemoselective reduction of **8** and **9** with tributyltin hydride afforded the corresponding derivatives **10** and **11** in excellent yields; finally, treatment of the ester **10** with bromine led us to isolate the tetracyclic

Scheme III



δ-bromo lactone **12** (Scheme II).

If the observed preference for endo addition with respect to the electron-withdrawing substituents is mainly due to secondary orbital interactions, we must conclude that these groups largely prevail, to this purpose, over the PhC=NO system of the starting isoxazole derivatives.

All the spectral data of the new compounds (Experimental Section) were in agreement with the assigned structures, and the most diagnostic ones are discussed below.

Whereas the absorptions of the CO_2Et, COPh, and NO_2 groups could be easily identified in the IR spectra of the primary cycloadducts, the off-resonance ^{13}C NMR spectra of the same compounds showed characteristic singlets in the range δ 94.8–107.8 for the quaternary carbons bonded to the above substituents; the assignment of these resonances was unambiguously achieved by comparison of the patterns of the nitro esters **3**, **6a,b**, and **8** with those of the corresponding nitro ketones **4**, **7a,b**, and **9**.

The proportions of the regioisomers in the adducts **6a,b** and **7a,b** were inferred from the relative intensities of the ^1H and ^{13}C resonances of the vinyl and methyl protons, and the CH olefinic carbons, respectively.

The structures **6a** and **7a** for the predominant regioisomers were deduced from ^{13}C NMR evidence by the following considerations:

(a) The well-separated methylene resonances of the above products (δ 28.6 and 29.0 vs 39.3 and 42.2) were easily assigned to the C-4 and C-7 carbons, respectively, on the basis of the sensible difference of the chemical shifts for the latter two ($\Delta\delta$ = 2.9 ppm), due to the variable group at position 7a.

(b) The components of the C-4 and C-7 triplets in the coupled spectra appear as doublets and multiplets, respectively, clearly indicating the relative position of the vinyl proton and the methylene group on the carbocyclic ring.

With regard to the cycloadducts **8** and **9**, the comparison of their ^1H NMR spectra strongly suggested the assigned structures; in fact, whereas the patterns at high field for the bridge methylene protons were almost identical, sensible shifts were observed for the H-1 and H-9 signals on going from **8** to **9**, due to the different anisotropic effects of the endo ester and benzoyl groups, respectively, at position 2.

This suggestion was corroborated by decoupling experiments on compounds **10** and **11** whose ^1H NMR spectra were characterized by a doublet of doublets for the H-6 proton at δ 4.14 and 4.54, respectively: irradiation of the H-7 multiplets at higher field caused the above signals to collapse to doublets with coupling constants ($^4J_{6,11b}$ =

(4) A mechanistic study of this interesting elimination process will be published elsewhere.

(5) Very small quantities of the corresponding "elimination products" were detected spectroscopically.

(6) Corey, E. J.; Estreicher, H. *Tetrahedron Lett.* **1981**, *22*, 603.

(7) Wenkert, E.; Moeller, P. D. R.; Piettre, S. R. *J. Am. Chem. Soc.* **1988**, *110*, 7188.

(8) (a) Ono, N.; Miyake, H.; Tamura, R.; Kaji, A. *Tetrahedron Lett.* **1981**, *22*, 1705. (b) Ono, N.; Miyake, H.; Kaji, A. *J. Chem. Soc., Chem. Commun.* **1982**, 33.

1.8 and 1.75 Hz, respectively) highly indicative of an endo configuration for the above proton[9] (Scheme III).

Finally, the δ-lactone structure of the bromo derivative **12**, whose formation definitively confirmed the stereochemistry of the esters **8** and **10**, appeared to be preferred to the corresponding γ-lactone **13** on the basis of the criteria recently advanced by Garratt for a spectral identification of isomeric tricyclic halo lactones.[10] Particularly, the lack of any coupling between H-9 and H-10 better agrees with the former structure showing a dihedral angle of nearly 90°, which sensibly increases for the corresponding H-13 and H-9 protons of compound **13**; on the other hand, the same structure well accounts for the upfield shift observed for both the C-12 and C-13 resonances with respect to those of the analogous C-10 and C-11 carbons of the precursor **10**, due to the twisting of the bridge methylene groups.

In conclusion, this work emphasizes a novel facet of the isoxazole system which can act as a dienophile in [2 + 4] cycloaddition processes with different dienes, through a suitably activated C(4)-C(5) double bond.

Experimental Section

Melting points, taken on a Büchi 510 apparatus, are uncorrected. Except where otherwise stated, infrared spectra were measured for dispersions in KBr with a Perkin-Elmer 283 spectrometer. ^{1}H NMR spectra were recorded in $CDCl_3$ solutions on Perkin-Elmer R32 and Varian VXR-300 instruments, operating at 90 and 300 MHz, respectively; ^{13}C NMR spectra were determined in the same solvent on a Varian FT-80A (20 MHz) machine. Elemental analyses were obtained by a Perkin-Elmer 240C Analyzer. Silica gel plates (Merck F_{254}) and silica gel 60 (Merck; 230–400 mesh) were used for analytical and flash chromatographies, respectively.

Cycloaddition Reactions of Compounds 1 and 2. General Procedure. A solution of the nitroisoxazole (1 mmol) and the diene (5 mmol) in toluene (1 mL) was heated in a sealed tube at 110–115 °C for 48 h. Evaporation to dryness under reduced pressure left a residue which was subjected to flash chromatography; the yields of the reaction products were determined on the basis of the recovered starting materials.

A. Chromatographic workup (toluene as eluent) of the raw product obtained from **1** and DMB afforded, in order of decreasing mobility, the starting nitro ester (0.13 g) and 4,7-dihydro-5,6-dimethyl-3-phenyl-1,2-benzisoxazole (**5**) (0.01 g, 9%) that was crystallized from petroleum ether as colorless needles: mp 95–96 °C; IR 1645, 1585, 1470, 1450, and 1355 cm^{-1}; ^{1}H NMR (90 MHz) δ 1.80 (br s, 6 H, 2 CH_3), 3.29 (br s, 4 H, 2 CH_2), 7.40–7.55 (m, 3 H, Ar H_3), 7.75–7.89 (m, 2 H, Ar H_2); ^{13}C NMR δ 18.7 (q, 5-CH_3/6-CH_3), 19.0 (q, 6-CH_3/5-CH_3), 29.85 (t, C-4/C-7), 30.3 (t, C-7/C-4), 108.8 (s, C-3a), 121.0 (s, C-5/C-6), 123.6 (s, C-6/C-5), 127.2 (d), 128.7 (d), 129.3 (d), 129.8 (s) (Ph), 158.9 (s, C-3), 166.7 (s, C-7a). Anal. Calcd for $C_{15}H_{15}NO$: C, 79.97; H, 6.71; N, 6.22. Found: C, 79.84; H, 6.62; N, 6.48.

The slowest moving band gave ethyl (3a*SR*,7a*RS*)-5,6-dimethyl-3a-nitro-3-phenyl-3a,4,7,7a-tetrahydro-1,2-benzisoxazole-7a-carboxylate (**3**) (0.15 g, 87%) as a white solid: mp 81–82 °C (from petroleum ether); IR 1735 (CO), 1560, and 1352 cm^{-1} (NO_2); ^{1}H NMR (90 MHz) δ 1.29 (t, J = 7 Hz, 3 H, OCH_2CH_3), 1.47 (br s, 3 H, 5-CH_3/6-CH_3), 1.77 (br s, 3 H, 6-CH_3/5-CH_3), 2.50–3.88 [m (two partially overlapped AB systems), J_{AB} = 17 Hz, 4 H, 2 CH_2], 4.24 (q, J = 7 Hz, 2 H, OCH_2CH_3), 7.30–7.70 (m, 5 H, Ph); ^{13}C NMR δ 13.5 (q, OCH_2CH_3), 18.5 (q, 5-CH_3/6-CH_3), 18.85 (q, 6-CH_3/5-CH_3), 35.05 (t, C-4), 40.8 (t, C-7), 62.7 (t, OCH_2CH_3), 94.8 (s, C-7a), 104.4 (s, C-3a), 123.8 (s, C-5/C-6), 126.1 (s), 126.5 (d) (Ph), 127.05 (s, C-6/C-5), 128.9 (d), 130.6 (d) (Ph), 153.5 (s, C-3), 167.8 (s, CO). Anal. Calcd for $C_{18}H_{20}N_2O_5$: C, 62.78; H, 5.85; N, 8.13. Found: C, 62.52; H, 5.77; N, 8.25.

B. The residue coming from the reaction of the nitro ketone **2** with DMB was resolved into three components with 75–120 °C ligroin/toluene (2:1 v/v) as eluent. After the fastest running band gave the starting material (0.106 g), the second one afforded (3a*SR*,7a*RS*)-7a-benzoyl-5,6-dimethyl-3a-nitro-3-phenyl-3a,4,7,7a-tetrahydro-1,2-benzisoxazole (**4**) (0.144 g, 60%) that was crystallized from petroleum ether as white needles: mp 134–135 °C; IR 1682 (CO), 1560, and 1355 cm^{-1} (NO_2); ^{1}H NMR (90 MHz) δ 1.47 (br s, 3 H, 5-CH_3/6-CH_3), 1.77 (br s, 3 H, 6-CH_3/5-CH_3), 2.60–3.50 [m (two partially overlapped AB systems), J_{AB} = 17 Hz, 4 H, 2 CH_2], 7.30–7.65 (m, 8 H, Ph and Ar H_3), 8.0–8.17 (m, 2 H, Ar H_2); ^{13}C NMR δ 18.7 (q, 5-CH_3/6-CH_3), 19.0 (q, 6-CH_3/5-CH_3), 35.4 (t, C-4), 43.6 (t, C-7), 100.9 (s, C-7a), 105.5 (s, C-3a), 124.3 (s, C-5/C-6), 126.1 (s), 126.6 (d) (Ph), 127.0 (s, C-6/C-5), 128.1 (d), 129.0 (d), 130.0 (d), 130.8 (d), 133.4 (d), 135.05 (s) (Ph), 154.45 (s, C-3), 198.7 (s, CO). Anal. Calcd for $C_{22}H_{20}N_2O_4$: C, 70.20; H, 5.36; N, 7.44. Found: C, 70.10; H, 5.51; N, 7.57.

Finally, the slowest moving band yielded the dihydro derivative **5** (0.03 g, 21%), identical (IR and ^{1}H NMR) with the material obtained as above.

C. Treatment of **1** with isoprene afforded a reaction mixture which was resolved into two components with 40–70 °C petroleum ether/ethyl acetate (8:1 v/v) as eluent. After the unreacted nitro ester (0.197 g) was recovered from the first band, the following one gave a 5:1 mixture of ethyl (3a*SR*,7a*RS*)-6-methyl-3a-nitro-3-phenyl-3a,4,7,7a-tetrahydro-1,2-benzisoxazole-7a-carboxylate (**6a**) and ethyl (3a*SR*,7a*RS*)-5-methyl-3a-nitro-3-phenyl-3a,4,7,7a-tetrahydro-1,2-benzisoxazole-7a-carboxylate (**6b**) as a yellow oil (0.054 g, 66%): IR (CCl_4) 1740 (CO), 1555, and 1360 cm^{-1} (NO_2); ^{1}H NMR (90 MHz) δ 1.29 (t, J = 7 Hz, 3 H, OCH_2CH_3) [1.53 (br s, 3 H, 5-CH_3)], 1.83 (br s, 3 H, 6-CH_3), 2.55–3.35 (m, 4 H, 2 CH_2), 4.27 (q, J = 7 Hz, 2 H, OCH_2CH_3), 5.48 (br s, 1 H, H-5) [5.71 (br s, 1 H, H-6), 7.45 (br s, 5 H, Ph); ^{13}C NMR δ 13.5 (q, OCH_2CH_3) [22.3 (q, 5-CH_3)], 22.65 (q, 6-CH_3), 28.6 (t, C-4) [33.3 (t, C-4)] [34.7 (t, C-7)], 39.3 (t, C-7), 62.7 (t, OCH_2CH_3) [94.2 (s, C-7a)], 94.4 (s, C-7a), 104.3 (s, C-3a), 116.4 (d, C-5) [119.8 (d, C-6)], 126.0 (s), 126.6 (d), 128.85 (d), 130.6 (d) (Ph) [133.5 (s, C-5)], 136.7 (s, C-6), 153.7 (s, C-3) [167.8 (s, CO)], 167.9 (s, CO).[11] Anal. Calcd for $C_{17}H_{18}N_2O_5$: C, 61.87; H, 5.49; N, 8.48. Found: C, 61.67; H, 5.85; N, 8.23.

D. Chromatographic resolution [toluene/75–120 °C ligroin (10:1 v/v) as eluent] of the raw product obtained from **2** and isoprene afforded the starting nitro ketone (0.19 g) and then a 5:1 mixture of (3a*SR*,7a*RS*)-7a-benzoyl-6-methyl-3a-nitro-3-phenyl-3a,4,7,7a-tetrahydro-1,2-benzisoxazole (**7a**) and (3a*SR*,7a*RS*)-7a-benzoyl-5-methyl-3a-nitro-3-phenyl-3a,4,7,7a-tetrahydro-1,2-benzisoxazole (**7b**) as a pale yellow solid (0.3 g, 23%) that was crystallized from hexane as white needles: mp 94–95 °C; IR 1680 (CO), 1552, and 1355 cm^{-1} (NO_2); ^{1}H NMR (90 MHz) δ [1.53 (br s, 3 H, 5-CH_3)], 1.82 (br s, 3 H, 6-CH_3), 2.68–3.50 (m, 4 H, 2 CH_2), 5.46 (br s, 1 H, H-5) [5.70 (br s, 1 H, H-6)], 7.30–7.70 (m, 8 H, Ph and Ar H_3), 8.05–8.18 (m, 2 H, Ar H_2); ^{13}C NMR δ [22.4 (q, 5-CH_3)], 22.7 (q, 6-CH_3), 29.0 (t, C-4) [33.8 (t, C-4)] [37.5 (t, C-7)], 42.2 (t, C-7), 100.25 (s, C-7a), 105.15 (s, C-3a), 116.8 (d, C-5) [119.6 (d, C-6)], 126.0–134.8 (2 Ph) [133.5 (s, C-5)], 136.3 (s, C-6), 154.9 (s, C-3), 198.5 (s, CO). Anal. Calcd for $C_{21}H_{18}N_2O_4$: C, 69.60; H, 5.01; N, 7.73. Found: C, 69.92; H, 5.10; N, 7.78.

E. The reaction product of **1** with cyclohexa-1,3-diene was resolved into two components with 40–70 °C petroleum ether/ethyl acetate (8:1 v/v) as eluent: whereas the first band gave the starting nitro ester (0.155 g) the second one afforded ethyl (2*SR*,6*RS*)-6-nitro-5-phenyl-3-oxa-4-azatricyclo[5.2.2.0^{2,6}]undeca-4,8-diene-2-carboxylate (**8**) (0.1 g, 72%) that was crystallized from petroleum ether as white needles: mp 92.5–93.5 °C; IR 1740 (CO), 1565, and 1365 cm^{-1} (NO_2); ^{1}H NMR (300 MHz) δ 1.16–1.39 (m, 2 H, H-10b and H-11b), 1.27 (t, J = 7 Hz, 3 H, OCH_2CH_3), 1.43–1.53 (m, 1 H, H-11a), 1.91–2.02 (m, 1 H, H-10a), 3.20–3.25 (m, 1 H, H-1), 3.68–3.73 (m, 1 H, H-7), 4.15–4.25 (m, 2 H, OCH_2CH_3), 6.36 (t, $J_{8,9}$ = $J_{1,9}$ = 7.2 Hz, 1 H, H-9), 6.65 (t, $J_{8,9}$ = $J_{7,8}$ = 7.2 Hz, 1 H, H-8), 7.37–7.50 (m, 3 H, Ar H_3), 7.61–7.65 (m, 2 H, Ar H_2); ^{13}C NMR δ 13.5 (q, OCH_2CH_3), 17.0 (t, C-10), 21.5 (t, C-11), 34.1 (d, C-7), 38.2 (d, C-1), 62.55 (t, OCH_2CH_3), 97.1 (s, C-2), 107.7 (s, C-6), 125.85 (d), 126.4 (s), 129.0 (d) (Ph), 129.75

(9) Ibuka, T.; Mori, Y.; Aoyama, T.; Inubushi, Y. *Chem. Pharm. Bull.* **1978**, *26*, 456 and references cited therein.

(10) Garratt, D. G.; Ryan, M. D.; Beaulieu, P. L. *J. Org. Chem.* **1980**, *45*, 839.

(11) The values in square brackets refer to the minor regioisomer.

(d, Ph/C-8/C-9), 130.2 (d, Ph/C-8/C-9), 130.8 (d, Ph/C-8/C-9), 153.0 (s, C-5), 166.85 (s, CO). Anal. Calcd for $C_{18}H_{18}N_2O_5$: C, 63.15; H, 5.30; N, 8.18. Found: C, 63.33; H, 5.41; N, 8.32.

F. Chromatographic workup [toluene/75–120 °C ligroin (10:1 v/v) as eluent] of the reaction product of **2** with the same diene yielded the unreacted starting material (0.2 g) and then (2*SR*,6*RS*)-2-benzoyl-6-nitro-5-phenyl-3-oxa-4-azatricyclo-[5.2.2.$0^{2,6}$]undeca-4,8-diene (**9**) (0.075 g, 63%) as a pale yellow solid that was crystallized from ether as white needles: mp 205–206 °C; IR 1690 (CO), 1560, and 1360 cm^{-1} (NO_2); ^1H NMR (300 MHz) δ 1.24–1.60 (m, 3 H, H-10b, H-11a, and H-11b), 2.04–2.18 (m, 1 H, H-10a), 3.38–3.45 (m, 1 H, H-1), 3.75–3.81 (m, 1 H, H-7), 6.22 (t, $J_{8,9} = J_{1,9} = 7.3$ Hz, 1 H, H-9), 6.79 (t, $J_{8,9} = J_{7,8} = 7.3$ Hz, 1 H, H-8), 7.38–7.66 (m, 8 H, Ph and Ar H_3), 7.99–8.04 (m, 2 H, Ar H_2); ^{13}C NMR δ 16.6 (t, C-10), 22.0 (t, C-11), 34.2 (d, C-7), 39.7 (d, C-1), 102.7 (s, C-2), 107.8 (s, C-6), 125.85 (d), 126.3 (s), 128.1 (d) (Ph), 128.7 (d, Ph/C-8/C-9), 129.2 (d), 129.9 (d) (Ph), 131.0 (d, Ph/C-8/C-9), 131.5 (d, Ph/C-8/C-9), 133.0 (d, Ph/C-8/C-9), 135.1 (s) (Ph), 154.0 (s, C-5), 194.9 (s, CO). Anal. Calcd for $C_{22}H_{18}N_2O_4$: C, 70.58; H, 4.85; N, 7.48. Found: C, 70.60; H, 4.86; N, 7.16.

Ethyl (2*SR*,6*SR*)-5-Phenyl-3-oxa-4-azatricyclo-[5.2.2.$0^{2,6}$]undeca-4,8-diene-2-carboxylate (10). Tributyltin hydride (0.25 g, 0.23 mL, 0.86 mmol) and azobisisobutyronitrile (AIBN, 0.011 g, 0.061 mmol) were added under nitrogen to a suspension of the cycloadduct **8** (0.204 g, 0.6 mmol) in anhydrous benzene (10 mL), and the mixture was refluxed for 2 h. Evaporation to dryness under reduced pressure left a residue, which was subjected to flash chromatography with 40–70 °C petroleum ether/ethyl acetate (7:1 v/v) as eluent; the faster moving band afforded the ester **10** [0.154 g, 91% yield based on the starting material recovered from the slower running fractions (0.01 g)] as a white solid: mp 129.5–130 °C (from ether); IR 1735 cm^{-1} (CO); ^1H NMR (300 MHz) δ 1.05–1.23 (m, 2 H, H-10b and H-11b), 1.28 (t, $J = 7$ Hz, 3 H, OCH_2CH_3), 1.42–1.50 (m, 1 H, H-11a), 2.04–2.12 (m, 1 H, H-10a), 3.02–3.08 (m, 1 H, H-7), 3.23–3.28 (m, 1 H, H-1), 4.14 (dd, $J_{6,7} = 3.7$ Hz, $J_{6,11b} = 1.8$ Hz, 1 H, H-6), 4.17–4.28 (m, 2 H, OCH_2CH_3), 6.30 (t, $J_{8,9} = J_{1,9} = 7.2$ Hz, 1 H, H-9), 6.41 (t, $J_{8,9} = J_{7,8} = 7.2$ Hz, 1 H, H-8), 7.39–7.46 (m, 3 H, Ar H_3), 7.69–7.76 (m, 2 H, Ar H_2); ^{13}C NMR δ 13.9 (q, OCH_2CH_3), 17.9 (t, C-10), 20.25 (t, C-11), 30.6 (d, C-7), 35.0 (d, C-1), 56.0 (d, C-6), 61.6 (t, OCH_2CH_3), 93.1 (s, C-2), 126.7 (d), 128.6 (d and s), 129.95 (d) (Ph), 132.1 (d, C-9), 134.6 (d, C-8), 156.8 (s, C-5), 170.4 (s, CO). Anal. Calcd for $C_{18}H_{19}NO_3$: C, 72.71; H, 6.44; N, 4.71. Found: C, 72.45; H, 6.40; N, 4.69.

(2*SR*,6*SR*)-2-Benzoyl-5-phenyl-3-oxa-4-azatricyclo-[5.2.2.$0^{2,6}$]undeca-4,8-diene (11). Operating as above, treatment of **9** (0.23 g, 0.61 mmol) with tributyltin hydride (0.27 g, 0.25 mL, 0.93 mmol) and AIBN (0.011 g, 0.061 mmol) in the same solvent (20 mL) gave a raw product, which was purified by flash chromatography with 40–70 °C petroleum ether/ethyl acetate (6:1 v/v) as eluent: the first band gave compound **11** [0.156 g, 87% yield based on the starting nitro ketone recovered from the second one (0.026 g)] that was crystallized from ether as white needles: mp 158–159 °C; IR 1688 cm^{-1} (CO); ^1H NMR (300 MHz) δ 1.13–1.28 (m, 2 H, H-10b and H-11b), 1.52–1.62 (m, 1 H, H-11a), 2.30–2.41 (m, 1 H, H-10a), 3.12–3.18 (m, 1 H, H-7), 3.33–3.38 (m, 1 H, H-1), 4.54 (dd, $J_{6,7} = 3.6$ Hz, $J_{6,11b} = 1.75$ Hz, 1 H, H-6), 6.08 (t, $J_{8,9} = J_{1,9} = 7$ Hz, 1 H, H-9), 6.45 (t, $J_{8,9} = J_{7,8} = 7$ Hz, 1 H, H-8), 7.40–7.61 (m, 6 H, 2 Ar H_3), 7.74–7.78 (m, 2 H, Ar H_2), 8.18–8.21 (m, 2 H, Ar H_2); ^{13}C NMR δ 18.1 (t, C-10), 20.3 (t, C-11), 30.5 (d, C-7), 37.4 (d, C-1), 54.2 (d, C-6), 98.7 (s, C-2), 126.7 (d), 128.6 (d and s), 130.0 (d), 130.2 (d) (Ph), 130.7 (d, C-9), 132.85 (d), 133.7 (s) (Ph), 134.9 (d, C-8), 157.2 (s, C-5), 195.9 (s, CO). Anal. Calcd for $C_{22}H_{19}NO_2$: C, 80.22; H, 5.81; N, 4.25. Found: C, 80.41; H, 5.86; N, 4.14.

Bromolactonization of the Ester 10. Bromine (0.058 g, 0.72 mmol) in chloroform (0.5 mL) was added dropwise to an ice-cooled solution of **10** (0.195 g, 0.66 mmol) in the same solvent (5 mL), and the mixture was stirred at room temperature until the starting material was completely consumed (18 h). The resulting solution was washed with aqueous $NaHCO_3$ (10%; 2 × 10 mL) and water (2 × 10 mL), dried, and evaporated to dryness; flash chromatography of the solid residue with 40–70 °C petroleum ether/ethyl acetate (5:1 v/v) as eluent afforded (2*SR*,10*RS*)-10-bromo-3-phenyl-5,8-dioxa-4-azatetracyclo[7.4.0.$0^{2,6}$.$0^{6,11}$]tridec-3-en-7-one (**12**) ($R_f = 0.46$; 0.05 g, 22%), that was crystallized from ether as white needles: mp 249–250 °C; IR 1800 cm^{-1} (CO); ^1H NMR (300 MHz) δ 1.29–1.42 (m, 1 H, H-13b), 1.75–1.88 (m, 1 H, H-13a), 1.91–2.06 (m, 2 H, H-12a and H-12b), 2.72–2.78 (m, 2 H, H-1 and H-11), 4.08 (dd, $J_{1,2} = 4.0$ Hz, $J_{2,13b} = 2.1$ Hz, 1 H, H-2), 4.32 (br d, $J_{10,11} = 3.9$ Hz, 1 H, H-10), 4.91 (d, $J_{1,9} = 5.6$ Hz, 1 H, H-9), 7.42–7.52 (m, 3 H, Ar H_3), 7.59–7.65 (m, 2 H, Ar H_2); ^{13}C NMR δ 11.5 (t, C-12), 15.4 (t, C-13), 32.7 (d, C-11), 36.85 (d, C-1), 48.1 (d, C-10), 53.4 (d, C-2), 80.2 (d, C-9), 83.1 (s, C-6), 126.65 (d), 127.5 (s), 129.1 (d), 130.9 (d) (Ph), 155.6 (s, C-3), 171.7 (s, CO). Anal. Calcd for $C_{16}H_{14}NO_3Br$: C, 55.19; H, 4.05; N, 4.02. Found: C, 54.92; H, 3.93; N, 4.23.

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Registry No. 1, 99934-18-6; **2**, 121246-80-8; **3**, 124286-99-3; **4**, 124287-00-9; **5**, 108735-45-1; **6a**, 124287-01-0; **6b**, 124287-09-8; **7a**, 124287-02-1; **7b**, 124287-08-7; **8**, 124287-03-2; **9**, 124287-04-3; **10**, 124287-05-4; **11**, 124316-36-5; **12**, 124287-06-5; **13**, 124287-07-6; DMB, 513-81-5; $H_2C{=}C(CH_3)CH{=}CH_2$, 78-79-5; cyclohexa-1,3-diene, 592-57-4.