Synthesis of Bicyclobutylidene, 1,3-Bis(trimethylene)propadiene, and 1,4-Bis(trimethylene)butatriene[1]

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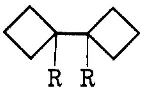
Two synthetic routes to bicyclobutylidene are described. Bicyclobutylidene can be readily epoxidized to 9-oxadispiro[3.0.3.1]nonane, and adds methylene to give dispiro[3.0.3.1]nonane and dibromocarbene to give the corresponding 9,9-dibromide. Reaction of the dibromide with methyllithium generated 1,3-bis(trimethylene)propadiene. This allene also reacted with dibromocarbene to give the mono- and bis adducts. Treatment of the monoadduct with methyllithium gave 1,4-bis(trimethylene)butatriene, and similar treatment of the bis adduct provided some evidence for the generation of 1,5-bis(trimethylene)pentatetraene.

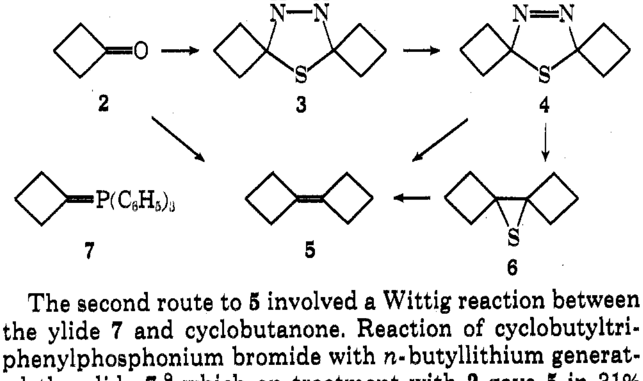
Although bicyclobutyl (**1a**)[2] and 1,1′-bicyclobutyldiol (**1b**)[3] have been known for some time, bicyclobutylidene (**5**) remained as one of the last simple ethylene derivatives which had not been prepared. The absence of a synthesis of **5** was probably due to the combination of the ease with which the cyclobutane ring rearranges,[4] together with the lack of a method of forming four-membered rings of comparable generality to that of carbene additions to olefins to give cyclopropanes.[5] We now report two synthetic routes to bicyclobutylidene, and describe some of its chemistry and its conversion into 1,3-bis(trimethylene)propadiene (**11**) and 1,4-bis(trimethylene)butatriene (**14**).[6]



1a, R = H
b, R = OH

The first synthetic route[1] to **5** utilized the olefin synthesis recently described by Barton[7] and Kellogg[8] and their respective coworkers. Reaction of cyclobutanone (**2**) with hydrazine hydrate and H_2S at −20° gave the thiadiazolidine **3**, mp 96–97°, in 82% yield. Oxidation of **3** with lead tetraacetate gave the thiadiazoline **4**, mp 72–73°, in 92% yield. Compound **4** was more stable than **3**, the latter compound decomposing with evolution of hydrogen sulfide. Reaction of **4** with triphenylphosphine gave bicyclobutylidene (**5**) as a colorless oil in 90% yield. The NMR spectrum had absorptions at τ 7.34–7.64 (allylic) and 7.88–8.28 (methylene) in the ratio 2:1, and the simple ir spectrum showed bands at 2930, 1425, 1035, and 915 cm^{-1}. The electronic spectra had its main maximum at 203 nm (see Figure 1).

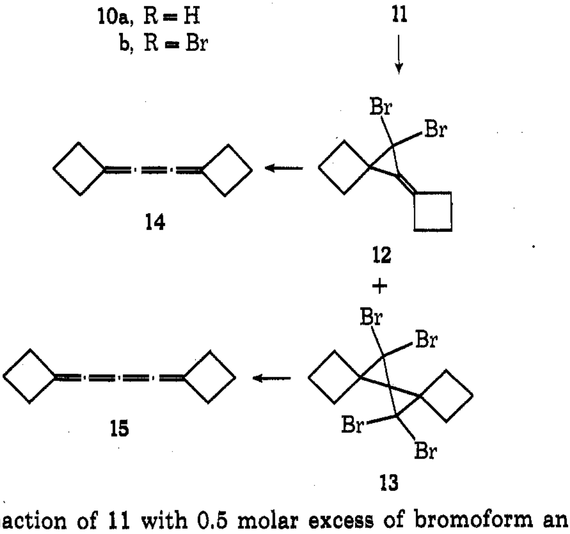
When **4** was heated in the absence of triphenylphosphine, **6**, mp 36–37°, was obtained in 98% yield. Reaction of **6** with triphenylphosphine at 85° again gave **5**.



The second route to **5** involved a Wittig reaction between the ylide **7** and cyclobutanone. Reaction of cyclobutyltriphenylphosphonium bromide with *n*-butyllithium generated the ylide **7**,[9] which on treatment with **2** gave **5** in 31% yield, identical in all observed respects with that obtained previously. The Wittig method appears to be the synthetic route of choice for the preparation of large amounts of **5** despite the somewhat lower yield.[10]

Compound **5** was oxidized by *m*-chloroperoxybenzoic acid to give the epoxide **8**, a colorless liquid, in 57% yield. When **8** was heated to 200° for 8 hr it was quantitatively rearranged to the known spiro[3.4]octan-5-one (**9**).[3]

Reaction of **5** with methylene iodide in the presence of a zinc-copper couple[11] gave **10a** as a colorless liquid in 35% yield. Similarly, reaction of **5** with bromoform and potassium *tert*-butoxide in pentane gave **10b**, mp 42–43°, in 84% yield. Treatment of **10b** with methyllithium gave 1,3-bis(trimethylene)propadiene (**11**) as a colorless liquid in 83% yield. The NMR spectrum ($CDCl_3$) showed a triplet at τ 6.9–7.6 and a multiplet at τ 7.8–8.45 in the ratio of 2:1.

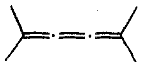


Reaction of **11** with 0.5 molar excess of bromoform and potassium *tert*-butoxide gave the dibromocyclopropane adduct **12** as a colorless liquid in 89% yield. Treatment of **12** with methyllithium at −10° gave 1,4-bis(trimethylene)butatriene (**14**). The cumulene **14** is relatively stable in solution at 0° and below, and it can be isolated as a crystalline compound. However, it rapidly forms an insoluble polymer in the latter state, probably by reaction with oxygen. The

NMR spectrum ($CDCl_3$, −50°) showed a triplet at τ 6.84–7.37 and a multiplet at τ 7.70–8.34, and the ir spectrum showed a weak cumulene band at 2230 cm^{-1}.

When **11** was treated with a five molar excess of bromoform and potassium *tert*-butoxide, a mixture of **12** and the bis(dibromocarbene) adduct **13** was obtained, from which **13** could be separated. Reaction of **13** with methyllithium at low temperature led to a very unstable material, solutions of which had an electronic spectrum consistent with the formation of 1,5-bis(trimethylene)pentatetraene (**15**), but this material could not be characterized.

The compounds **11**, **14**, and **15** show a progressive decrease in stability and a greater reactivity toward oxygen. The electronic spectra of **11** and **14**, together with that of bicyclobutyldiene (**5**), are shown in Figure 1. The virtual coincidence of the first absorption bands of **5** and **11** finds ample precedent in the literature for other pairs of substituted ethenes and allenes.[12] The allene **11** shows a maximum absorption at 199 nm, at a similar wavelength to that observed for tetramethylallene (195.5 nm),[13] while the cumulene **14** shows two absorption bands characteristic of a tetrasubstituted butatriene. However, in comparison to tetramethylbutatriene (**16**),[14] which shows a maximum at 230 nm, the short-wavelength band of **14** shows a bathochromic displacement to 248 nm. The extinction coefficient of the long-wavelength bands of **14**, **16**, and tetra-*tert*-butylbutatriene (**17**)[15] increase from 10,300 for **14**, through 17,000 for **16**, to 34,900 for **17**. This increase in extinction coefficient is probably associated with the change in the C^1–C^2–C^3 bond angle θ (see **18**). In the case of **11** the angle θ is the internal angle of the four-membered ring and consequently approximates to 90°, in **16** the angle is presumably 120°, and in **17** it is probably greater than 120°, owing to steric repulsion of the *tert*-butyl groups.



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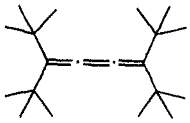

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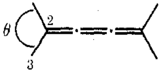

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Compounds **5** and **11** are now readily available, and we are currently studying their elaboration to other new systems containing four-membered rings.

Experimental Section

NMR spectrum were obtained on either a Varian T-60 or HA-100 spectrometer and are recorded in τ units with Me_4Si as internal standard. Mass spectra were taken on either an AEI MS-12 or MS-9 spectrometer. Infrared spectra were recorded on a Unicam SP-200 spectrophotometer, only strong and medium bands being reported. Electronic spectra were recorded on a Unicam SP 800 recording spectrometer, except for the spectra of **5** and **11**, which were recorded on a Cary 17 spectrometer, flushed with nitrogen, by Dr. A. F. Drake, King's College London. Solvents were purified by standard methods.

Synthesis of 5-Thia-10,11-diazadispiro[3.1.3.2]undecane (3). Hydrogen sulfide was bubbled through vigorously stirred cyclobutanone (21 g, 0.30 mol) for 20 min, and then aqueous hydrazine (20 ml, 7.5 *M* solution, 0.15 mol) was added dropwise over 20 min with continued passage of H_2S. After completion of the addition of hydrazine, H_2S was passed for a further 20 min, a solid product having formed. The crude reaction mixture was then treated with dichloromethane (200 ml), the organic layer was separated, and the aqueous layer was reextracted with CH_2Cl_2 (2 × 50 ml). The combined organic layers were dried ($MgSO_4$) and the solvent was removed under reduced pressure to give **3**, 21 g (82%), white crystals [petroleum ether (bp 40–60°)]: mp 96–97°, MS *m/e* 170.0868 (calcd for $C_8H_{14}N_2S$, 170.0878), 170 (M^+, 1), 142 ($M - N_2$, 68), 136 ($M - H_2S$, 24), 114 ($M - C_2H_4N_2$, 46), 113 (16), 104 (100); NMR (CCl_4) τ 7.36–8.39 (m, 12 H), 6.47 (br s, 2 H); ir (KBr) 3200, 2910, 1425, 1245, 1170, 1140, 1075, 950, 860, and 820 cm^{-1}.

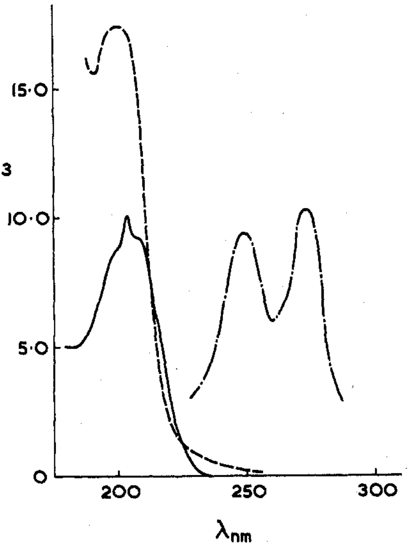

Figure 1. The electronic spectra of **5** (——) in isooctane, **11** (– – –) in isooctane, and **14** (– • –) in ether.

Oxidation of 3 to 5-Thia-10,11-diazadispiro[3.1.3.2]undecene-10 (4). Compound **3** (21 g, 0.12 mol) was dissolved in dry petroleum ether (800 ml), and the solution was then added slowly over 40 min to a vigorously stirred suspension of powdered lead tetraacetate (66 g, 0.15 mol) in dry petroleum ether (100 ml) at 0°. After completion of addition the reaction mixture was stirred for a further 40 min at 0°. The reaction mixture was filtered through Kieselguhr, and the precipitate was washed with petroleum ether (2 × 100 ml). The filtrates were combined, and the solvent was removed under reduced pressure to give **4**: 19.0 g (92%); white crystals (methanol); mp 72.5–73°; MS *m/e* 168 (M^+, 1), 140 ($M - N_2$, 48), 112 ($M - C_2H_4N_2$, 84), 111 (30), 97 (33), 91 (20), 80 (20), 79 (79), 77 (24), 61 (23), 58 (100); NMR (CCl_4) τ 7.04–7.76 (m, 10 H), 7.86–8.15 (m, 2 H); ir (KBr) 2950, 1565, 1425, 1250, 1090, 950, 880, and 800 cm^{-1}; λ_{max} (EtOH) 311 sh nm (ϵ 480), 292 (545), and 234 sh (370).

Anal. Calcd for $C_8H_{12}N_2S$: C, 57.11; H, 7.19; N, 16.65. Found: C, 56.67; H, 7.21; N, 17.06.

Conversion of 4 to Bicyclobutylidene (5). A mixture of powdered **4** (4.2 g, 0.025 mol) and dry triphenylphosphine (12.5 g, 0.075 mol) was heated at 85° for 1 hr under reduced pressure (100 mmHg). The voltatile liquid product was condensed from the evolved gases and purified by distillation over $MgSO_4$ to give bicyclobutylidene (**5**): 2.5 g (92%); bp ca 85° (100 mmHg); MS *m/e* 108 (M^+, 52), 93 (38), 80 ($M - C_2H_4$, 86), 79 (100); NMR, see discussion; ir, see discussion; λ_{max} (isooctane), see Figure 1.

Anal. Calcd for C_8H_{12}: C, 88.83; H, 11.18. Found: C, 88.86; H, 11.07.

Synthesis of Bicyclobutylidene (5) via the Wittig Reaction. Cyclobutyltriphenylphosphonium bromide (49.4 g, 0.12 mol) was suspended in dry tetrahydrofuran (600 ml). *n*-Butyllithium (55.5 ml, 2.2 *M* in *n*-hexane, 0.12 mol) was added to the stirred suspension and, after 15 min, all of the phosphonium bromide had dissolved. Cyclobutanone (7 g, 0.1 mol) in dry tetrahydrofuran (180 ml) was then added dropwise to the deep-red solution of the ylide over 45 min. The mixture was then stirred for a further 30 min at room temperature and then heated to 60–65° with stirring for 12 hr. The solution was allowed to cool, dichloromethane (240 ml) was added, and the mixture was extracted with water (5 × 100 ml). The organic layer was dried ($MgSO_4$) and distilled under reduced pressure, when triphenylphosphine oxide remained as the residue. Fractional distillation then gave **5**, 3.3 g (31%), identical in all observed respects with the previous sample.

Pyrolysis of 4. Synthesis of 9-Thiadispiro[3.0.3.1]nonane (6). Compound **4** (0.84 g, 5 mmol) was vigorously stirred and heated under dry nitrogen at 85° for 20 min. On cooling the melt solidified, and sublimation (40°, 50 mmHg) gave **6**: 0.68 g (98%); mp 36.5–37°; MS *m/e* 140 (M^+, 33), 112 ($M - C_2H_4$, 60), 111 (36), 107 (36), 97 (41), 91 (20), 84 (20), 80 (18), 79 (100); NMR (CCl_4) τ 7.30–8.28 (m); ir (film) 2950, 1440, 1390, 1235, 1195, 1075, 920, and 870 cm^{-1}; λ_{max} (EtOH) 263 nm (ϵ 37).

Oxidation of 5. Synthesis of 9-Oxadispiro[3.0.3.1]nonane (8). *m*-Chloroperoxybenzoic acid (2 g, 12 mmol) was dissolved in dry ether (35 ml) and cooled to 0° under dry nitrogen and bicyclobutylidene (**5**) (1.08 g, 10 mmol) was added dropwise over 30 min. The solution was then stirred at 0° for a further 8 hr and the reaction mixture was filtered through Kieselguhr. The precipitate was washed with dry ether (2 × 10 ml), and the combined filtrates were washed with aqueous sodium hydroxide (2 × 20 ml, 0.1 *M* solution), water made alkaline with ammonia (20 ml), and basic aqueous ferrous sulfate (~0.1 *M* solution) until no further color change occurred in the aqueous layer. After a final wash with water made basic with ammonia, the organic solution was dried ($MgSO_4$) and the solvent was removed under reduced pressure to a volume of ca. 2 ml. Preparative TCL on alumina, eluting with petroleum ether–ether (95:5), gave **8**, 0.71 g (57%), as a colorless liquid: NMR (CCl_4) τ 7.47–8.44; ir (film) 2930, 1505, 1430, 1240, 1125, 1100, 1050, 910, and 820 cm^{-1}.

Anal. Calcd for $C_8H_{12}O$: C, 77.37; H, 9.74. Found: C, 77.67; H, 9.78.

Thermolysis of 8 to 9. Compound **8** (0.062 g, 0.5 mmol) was degassed, sealed in vacuo, and heated at 200° for 8 hr. Separation by TLC on alumina gave **9** (0.060 g), the structure being confirmed by the mass spectrum and comparison of the ir spectrum with that of an authentic sample.

Reaction of 5 with Methylene. Synthesis of Dispiro[3.0.3.1]nonane (10a). A suspension of zinc–copper couple, prepared from zinc dust (3.5 g, 0.06 g-atom) and cupric acetate (0.05 g), in ether (10 ml), was stirred and heated to reflux, and a mixture of **5** (1.08 g, 10 mmol) and dry, redistilled diiodomethane (6.70 g, 30 mmol) was added dropwise. Heating was continued for a further 24 hr, and the mixture was then filtered through Kieselguhr and the filtrate was concentrated under reduced pressure to give an oil. Distillation under reduced pressure (20°, 1×10^{-4} mmHg) followed by preparative GLC (6 ft × 0.25 in., Apiezon, 120°, He 40 psi) gave **10a**, 0.43 g (35%), as a colorless liquid: MS *m/e* 122 (M^+, 20), 121 (6), 119 (15), 117 (15), 107 (9), 95 (12), 94 ($M - C_2H_4$, 100); NMR (CCl_4) τ 7.79–8.27 (m, 12 H), 9.72 (s, 2 H); ir (film) 2950, 1435, 1110, 1005, and 920 cm^{-1}.

Anal. Calcd for C_9H_{14}: C, 88.45; H, 11.55. Found: C, 88.13; H, 11.43.

Reaction of 5 with Dibromocarbene. Synthesis of 9,9-Dibromodispiro[3.0.3.1]nonane (10b). A mixture of **5** (1.08 g, 10 mmol), potassium *tert*-butoxide (4.48 g, 40 mmol), and petroleum ether (150 ml) was stirred at 0° under dry nitrogen. Bromoform (3.86 g, 15 mmol) in petroleum ether (5 ml) was added dropwise over 35 min. The mixture was then allowed to warm to room temperature and was stirred for a further 12 hr. The insoluble material was then removed by filtration, and the precipitate was washed with petroleum ether. The solvent was then removed from the combined organic layers under reduced pressure at 0°, to give a brown, crystalline product (2.6 g). Chromatography on silica gel, eluting with petroleum ether, gave **10b**: 2.33 g (84%); mp 42–47°; MS *m/e* 280; NMR (CCl_4) τ 7.7–8.3 (m); ir (KBr) 2920, 1430, 1240, 1090, 810, and 750 cm^{-1}.

Anal. Calcd for $C_9H_{12}Br_2$: C, 38.60; H, 4.32; Br, 57.08. Found: C, 38.24; H, 4.35; Br, 56.73.

Reaction of 10b with Methyllithium. Synthesis of 1,3-Bis(trimethylene)propadiene (11). The dibromide **10b** (560 mg, 2.0 mmol) was dissolved in dry ether (30 ml), stirred, and cooled to −70° under dry N_2. Methyllithium (11 ml, 2.3 *M* in ether, 25 mmol) was added in one portion, and the reaction mixture was then allowed to warm to −10° and stirred for 1 hr. Degassed water (20 ml) was added, the ethereal layer was separated, and the aqueous layer was extracted with ether (50 ml). The combined organic layers were extracted with degassed water (2 × 20 ml) and dried ($MgSO_4$). Evaporation of the solvent gave a pale yellow liquid, which was purified by bulb-to-bulb distillation to give the allene **11** (200 mg, 83%) as a colorless liquid: MS *m/e* 120; NMR, see discussion; ir (liquid film) 2950, 1420, 1230, 1050, and 880 cm^{-1}; λ_{max}, see discussion.

Anal. Calcd for C_9H_{12}: C, 89.94; H, 10.06. Found: C, 89.55; H, 9.95.

Reaction of 11 with Dibromocarbene. The allene **11** (110 mg, 0.9 mmol) and potassium *tert*-butoxide (370 mg, 3.3 mmol) were added to petroleum ether (bp <40°, 15 ml) and the suspension was stirred and cooled at 0° under N_2. Bromoform (370 mg, 1.5 mmol) in petroleum ether (3 ml) was then added dropwise over 30 min with continuous stirring, the mixture was allowed to warm to room temperature, and stirring was continued for a further 18 hr. The insoluble material was removed by filtration, the precipitate was washed with petroleum ether (10 ml), and the solvent was then removed from the combined filtrates by evaporation to give **12** as an oil (240 mg, 89%): MS *m/e* 292; NMR ($CDCl_3$) τ 6.76–7.18 (q, 4 H), 7.22–8.20 (m, 8 H); ir (liquid film) 2930, 1760, 1414, 1406, 1106, 1080, 1038, 958, 804, 705, and 720 cm^{-1}.

Anal. Calcd for $C_{10}H_{12}Br_2$: C, 41.12; H, 4.14; Br, 54.73. Found: C, 40.81; H, 4.03; Br, 55.07.

Reaction of the allene **11** (100 mg, 0.83 mmol) with a large excess of potassium *tert*-butoxide (1.5 g, 13 mmol) and bromoform (1.0 g, 4 mmol) under similar conditions gave a mixture of **12** and 10,10,11,11-tetrabromotrispiro[3.0.0.3.1.1]undecane (**13**), which was separated by distillation. Compound **13** (120 mg, 21%) was a colorless liquid: MS *m/e* 463.7633 (calcd for $C_{11}H_{12}Br_4$, 463.7635); NMR ($CDCl_3$) τ 7.66–8.12 (m, 2 H), 8.16–9.12 (m, 10 H); ir (liquid film) 2930, 1460, 1380, 1125, 1090, 1050, 1000, 980, 920, 870, 830, 775, 738, and 650 cm^{-1}. Compound **12** (60 mg, 33%).

Reaction of 12 with Methyllithium. Synthesis of 1,4-Bis(trimethylene)butatriene (14). Compound **12** (160 mg, 0.5 mmol) was dissolved in dry ether (20 ml) and the solution was stirred and cooled to −70° under N_2. Methyllithium (2 ml, 2.3 *M* in ether, 4.6 mmol) was added and the reaction mixture was allowed to warm to −10° and stirred for 1 hr. Degassed water (5 ml) was added, and the ethereal layer was separated, washed with degassed water (5 ml), and dried ($MgSO_4$). Evaporation of the solvent gave the cumulene **14** (50 mg, 69%) as a white solid which decomposed on attempted melting point determination: MS *m/e* 132.0939 (calcd for $C_{10}H_{12}$, 132.0942); NMR, see discussion; ir (KBr) 2930, 2230, 1700, 1670, 1463, 1420, 1290, 1240, 1118, 945, and 898 cm^{-1}; λ_{max} (Et_2O) 248 nm (ϵ 9400), 273 (10,300).

Reaction of 13 with Methyllithium. Compound **13** (20 mg, 0.04 mmol) was treated with methyllithium (0.2 ml, 2.3 *M* in ether, 0.46 mmol) under the same conditions as described for the previous experiment. The solutions were washed rapidly with cold, degassed water, and the ethereal solution was dried at −78°. Examination of the electronic spectrum of the dried ethereal solution showed two absorption maxima at 248.5 and 272 nm, with a possible third, much smaller maximum at ca. 300 nm. Concentration of the solution led to rapid decomposition of the product.

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Registry No.—**2**, 1191-95-3; **3**, 37677-05-7; **4**, 37676-86-1; **5**, 6708-14-1; **6**, 37677-08-0; **8**, 37677-06-8; **9**, 10468-36-7; **10a**, 37677-07-9; **10b**, 55319-56-7; **11**, 55319-57-8; **12**, 55319-58-9; **13**, 55319-59-0; **14**, 55319-60-3; methylene, 2465-56-7; dibromocarbene, 74-95-3; methyllithium, 917-54-4; bromoform, 75-25-2.

References and Notes

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