Reactions of 3-Isopropenyltropolones with Bromine and N-Bromosuccinimide: Formation of 8H-Cyclohepta[b]furan-8-one Derivatives

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3-Isopropenyltropolones 1a-c were treated with bromine in carbon tetrachloride to give 3-methyl-8H-cyclohepta[b]furan-8-ones 2a-c and their corresponding 7-bromo-substituted compounds 3a-c, while reactions in acetic acid gave the bromo-substituted compounds 3a-c. On the other hand, bromination of 1a-c with N-bromosuccinimide afforded 7-bromo-3-(2-bromo-1-methylethenyl)tropolones 5a-c. The compound 2a was treated with bromine to give 2-bromo-3-methyl-8H-cyclohepta[b]furan-8-one (4). The tropolones 5a-c were heated in the presence of potassium carbonate to give the cyclized compounds 3a-c.

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It is well-known that, on bromination with bromine, tropolones generally give substitution products [1-3]. On the other hand, the bromination of 4-isopropenyltropolone have been carried out [4]. As the results, it was reported that the treatment of the tropolone with bromine gave 4-(1,2-dibromoethyl)tropolone in carbon tetrachloride and 7-bromo-4-isopropenyl- and 7-bromo-4-(1,2-dibromoethyl)tropolone in acetic acid, whereas the reaction with N-bromosuccinimide (NBS) in carbon tetrachloride gave 7-bromo-4-isopropenyltropolone. In the connection, the bromination of 3-isopropenyltropolone, which has an isopropenyl group at the neighboring position to the tropolone hydroxyl group, is very interesting. In this paper, we carried out bromination reactions of a few 3-isopropenyltropolones and found that these tropolones gave substitution products at both the tropolone nucleus and the alkenyl side-chain, and cyclization products from the latter.

Results and Discussion.

Reactions of 3-Isopropenyltropolones la-c with Bromine.

A solution of 3-isopropenyltropolone (1a) in carbon tetrachloride was treated with an equimolar amount of bromine and chromatographed on silica gel to give 3-methyl-8H-cyclohepta[b]furan-8-one (2a) [5] and 5,7-dibromo-3-methyl-8H-cyclohepta[b]furan-8-one (3a) in 24 and 14% yield, respectively. Treatment with two molar equivalents of bromine improved the yields of 2a and 3a to 46 and 20%, respectively. These compounds showed no coloration with iron(III) chloride solution. The compound 2a was identified by comparison with an authentic sample, which was obtained by oxidation of 1a with peracid and 2,3-dichloro-5,6-dicyanobenzoquinone [5]. The compound 3a was confirmed by its spectral data and elemental

analysis. In the 'H nmr spectrum, a singlet peak was observed at δ 7.67 and assigned to H-2 proton. Two doublet peaks (J = 1.6 Hz) were observed at δ 7.74 and 8.48 and supported that two bromine atoms were substituted at the 5- and 7-positions. On the bromination with an equimolar amount of bromine, 3-isopropenyl-5-methyltropolone (1b) [6] gave 3,5-dimethyl-8H-cyclohepta[b]furan-8-one (2b) (23%) and its 7-bromo-1-substituted derivative 3b (39%), whereas 3-isopropenyl-5-isopropyltropolone (1c) [6] gave 5-isopropyl-3-methyl-8H-cyclohepta[b]furan-8-one (2c) (16%) and its 7-bromo-1-substituted derivative 3c (34%). The compound 2a was treated with bromine to give 2-bromo-3-methyl-8H-cyclohepta[b]furan-8-one (4) in 26% yield. The 'H nmr spectral pattern for the seven-membered ring protons is very similar to that of the starting material 2a and the signal for the H-2 proton disappeared in the spectrum of 4.

Scheme 2

The reaction of 3-isopropenyltropolone (1a) with an equimolar amount of bromine in acetic acid gave 5,7-dibromo-3-methyl-8H-cyclohepta[b]furan-8-one (3a) in 24% yield. The treatment with two molar equivalents of bromine afforded the compound 3a in 53% yield. Similarly, 5-alkyl-substituted tropolones 1b,c were cyclized with two molar equivalents of bromine to give the corresponding compound 3b,c in 44 and 72% yields, respectively.

In these reactions, the formation of 2a-c seemed to proceed through intermediates II (Scheme 3). The reaction would be initiated by electrophilic attack of bromine at the ω -position of the isopropenyl group to form intermediates II via I. This reaction is faciliated by the participation of a neighboring hydroxyl group. The intermediates II were cyclized to the products 2a-c by the nucleophilic attack of the hydroxyl oxygen atom to the ω -carbon atom bearing bromine atom followed by dehydrobromination. Such a process has been reported in the cyclization of 2-hydroxy- β -bromostyrenes to benzofuran derivatives [7,8]. The compounds 3a-c would be formed by bromination of la-c and the succesively cyclization as similar as the formation of 2a-c. This is supported by the fact that the treatment of 3-methyl-8H-cyclohepta[b]furan-8-one (2a) with bromine did not give 7-bromo- or 5,7-dibromo-3-methyl-8Hcyclohepta[b]furan-8-one (3a) but gave 2-bromo-3-methyl-8H-cyclohepta[b]furan-8-one (4).

Scheme 3

$$CH_3$$
 CH_3
 CH_3

Reactions of 3-Isopropenyltropolones la-c with NBS.

A mixture of 3-isopropenyltropolone (1a) and an equimolar amount of NBS in carbon tetrachloride was stirred for 1 hour at room temperature to afford 5,7-dibromo-3-(2-bromo-1-methylethenyl)tropolone (5a) in 31% yield. Bromination with two molar equivalents of bromine gave 5a in 60% yield. From the orientation in electrophilic substitution at the tropolone nucleus, it was expected that the bromo substituents should be present at 5-, 7-, and/or ω -position. The structure was confirmed on the basis of its spectral data and elemental analysis. The ir spectrum showed the tropolone hydroxyl and carbonyl absorptions at 3185 and 1600 cm⁻¹, respectively. This is also supported by coloration with iron(III) chloride solution. In the ¹H nmr spectrum, two doublet peaks (J = 1.6 Hz) at δ 7.67 and 8.32 showed that two bromine atoms are substituted

at the 5- and 7-positions. Another bromine atom is present on the side chain. This is supported by observation of a multiplet of the olefinic proton at δ 6.37. Further, the methyl signal at δ 2.11 (d, J = 1.8 Hz) showed that the olefinic proton is orientated in Z-form.

Bromination of 3-isopropenyl-5-methyltropolone (1b) also gave 7-bromo-3-(2-bromo-1-methylethenyl)-5-methyltropolone (5b) in 55% yield. However, 3-isopropenyl-5-isopropyltropolone (1c) afforded the corresponding substitution product 5c (11%) and additionally cyclized 7-bromo-5-isopropyl-3-methyl-8*H*-cyclohepta[b]furan-8-one (3c) (35%). In the reaction of the compound 1c, the formation of the cyclization product 3c might be attributed to releasing steric hindrance of the more bulky isopropyl group at the 5-position.

Cyclization of 3-(2-Bromo-1-methylethenyl)tropolones 5a-c.

A solution of 3-(2-bromo-1-methylethenyl)tropolone (5a) in carbon tetrachloride was refluxed for 3 hours in the presence of potassium carbonate to afford the cyclized compound 3a in 87% yield. The compounds 5b,c also gave the corresponding compounds 3b,c in 82 and 76% yields, respectively.

Azo-coupling Reactions and Nitration of 3-Isopropenyltropolone (1a).

In addition to the bromination reactions, a few electrophilic substitution reactions were carried out. Azocoupling reactions of 3-isopropenyltropolone (1a) with several arenediazonium ions gave the corresponding 5-arylazo-3-isopropenyltropolones 6a-f. The treatment of the compound 6b with bromine afforded the cyclized 7-bromo-3-methyl-5-(4-methylphenylazo)-8H-cyclohepta-[b]furan-8-one (7) in 49% yield. These structures were determined on the basis of their spectral data and elemental analyses.

Nitration of 3-isopropenyltropolone (1a) gave complex resinous material but no product was isolated.

Scheme 4

EXPERIMENTAL

Measurements.

The melting points were determined with a Yanagimoto MP-S3 apparatus and are uncorrected. The ir spectra were taken on a JASCO A-102 and a Perkin-Elmer 1730 spectrophotometer. The ¹H nmr spectra were measured with a JEOL JNM-PMX60SI spectrometer.

Reaction of 3-Isopropenyltropolones 1a-c with Bromine in Carbon Tetrachloride.

General Procedure.

To a stirred solution of 3-isopropenyltropolones la-c (2 mmoles) in carbon tetrachloride (5 ml) was added bromine (640 mg, 4 mmoles) in carbon tetrachloride (1 ml) at water-cooled temperature. After stirring for 1 hour, the mixture was poured into water (100 ml) and extracted with chloroform. The extract was washed with a sodium hydrogensulfite solution and water, and dried over sodium sulfate. The evaporated residue was chromatographed on two Wakogel B-10 plates (30 x 30 cm) with ethyl acetate and recrystallized from ethanol to give 3-methyl-8H-cyclohepta[b]furan-8-ones 2a-c and their bromo-substituted derivatives 3a-c.

3-Methyl-8H-cyclohepta[b]furan-8-one (2a).

This compound was obtained as pale orange-yellow prisms, mp 95-97° (lit [5], 95-96°).

3,5-Dimethyl-8H-cyclohepta[b]furan-8-one (2b).

This compound was obtained as pale yellow prisms, mp 160-161°; ir (chloroform): ν max 1625 cm⁻¹ (C=0); ¹H nmr (deuteriochloroform): δ 2.23 (3H, s, 3-CH₃), 2.44 (3H, s, 5-CH₃), 7.21 (3H, s, H-4, 6, 7), 7.64 (1H, s, H-2).

Anal. Calcd. for $C_{11}H_{10}O_2$: C, 75.84; H, 5.79. Found: C, 75.59; H, 5.81.

5-Isopropyl-3-methyl-8H-cyclohepta[b]furan-8-one (2c).

This compound was obtained as pale yellow prisms, mp 67-69°; ir (chloroform): ν max 1625 cm⁻¹ (C=0); ¹H nmr (deuteriochloroform) δ 1.29 [6H, d, J = 7.0 Hz, 5-C(CH₃)₂], 2.25 (3H, s, 3-CH₃), 2.93 (1H, sept, J = 7.0 Hz, 5-CH), 7.26 (3H, s, H-4, 6, 7), 7.65 (1H, brs, H-2).

Anal. Calcd. for C₁₃H₁₄O₂: C, 77.20; H, 6.98. Found: C, 77.09; H, 7.11.

5,7-Dibromo-3-methyl-8H-cyclohepta[b]furan-8-one (3a).

This compound was obtained as greenish yellow needles, mp 228-229°; ir (chloroform): ν max 1627 cm⁻¹ (C=0); ¹H nmr (deuteriochloroform): δ 2.23 (3H, s, CH₃), 7.67 (1H, s, H-2), 7.74 (1H, d, J = 1.6 Hz, H-6), 8.47 (1H, d, J = 1.6 Hz, H-4).

Anal. Calcd. for C₁₀H₆O₂Br₂: C, 37.77; H, 1.90. Found: C, 38.02; H, 1.95.

7-Bromo-3,5-dimethyl-8H-cyclohepta[b]furan-8-one (3b).

This compound was obtained as greenish yellow needles, mp 172-174°; ir (chloroform): ν max 1630 cm⁻¹ (C=0); ¹H nmr (deuteriochloroform): δ 2.23 (3H, s, 3-CH₃), 2.46 (3H, s, 5-CH₃), 7.21 (1H, d, J = 1.6 Hz, H-6), 7.62 (1H, s, H-2), 8.14 (1H, d, J = 1.6 Hz, H-4).

Anal. Calcd. for C₁₁H₉O₂Br: C, 52.20; H, 3.58. Found: C, 52.26; H, 3.47.

7-Bromo-5-isopropyl-3-methyl-8H-cyclohepta[b]furan-8-one (3c).

This compound was obtained as pale yellow prisms, mp 147-149°; ir (chloroform): ν max 1625 cm⁻¹ (C=0); ¹H nmr (deuteriochloroform): δ 1.28 [6H, d, J = 7.0 Hz, 5-C(CH₃)₂], 2.23 (3H, s, 3-CH₃), 2.95 (1H, sept, J = 7.0 Hz, 5-CH), 7.26 (1H, d, J = 1.6 Hz, H-6), 7.65 (1H, s, H-2), 8.19 (1H, d, J = 1.6 Hz, H-4).

Anal. Calcd. for C₁₃H₁₃O₂Br: C, 55.53; H, 4.66. Found: C, 55.83; H, 4.39.

Bromination of 3-Methyl-8H-cyclohepta[b]furan-8-one (2a) with Bromine.

To a stirred solution of 3-methyl-8*H*-cyclohepta[*b*]furan-8-one (2a) (160 mg, 1.0 mmole) in carbon tetrachloride (5 ml) was added bromine (160 mg, 1.0 mmoles) in carbon tetrachloride (1 ml). After stirring for 1 hour, the mixture was poured into water, extracted with chloroform, washed with sodium hydrogensulfite solution and water, and dried over sodium sulfate. The evaporated residue was chromatographed on a Wakogel B-10 plate (30 x 30 cm) with ethyl acetate to give 2-bromo-3-methyl-8*H*-cyclohepta[*b*]furan-8-one (4) as colorless micro-crystals, yield 61 mg (26%), mp 172-173°; ir (chloroform): *r* max 1625 cm⁻¹ (C = 0); ¹H nmr (deuteriochloroform): δ 2.18 (3H, s, CH₃), 6.8-7.5 (4H, m). *Anal.* Calcd. for C₁₀H₇O₂Br: C, 50.24; H, 2.95. Found: C, 49.83; H, 3.06.

Reaction of 3-Isopropenyltropolones la-c with Bromine in Acetic acid.

General Procedure.

To a stirred solution of 3-isopropenyltropolones la-c (10 mmoles) in acetic acid (30 ml) containing sodium acetate (1.2 g, 15 mmoles) was added bromine (3.2 g, 20 mmoles) in acetic acid (3 ml) at water-cooled temperature. After stirring for 1 hour, a yellowish orange precipitate was collected and dissolved in chloroform. The solution was washed with a sodium hydrogencarbonate solution, sodium hydrogensulfite solution, and water, and dried over sodium sulfate. The evaporated residue was recrystallized from ethanol to afford bromo-substituted-3-methyl-8H-cycloheptal b lfuran-8-ones 3a-c.

Reaction of 3-Isopropenyltropolones la-c with NBS.

General Procedure.

A mixture of 3-isopropenyltropolones **la-c** (5 mmoles) and NBS (1.78 g, 10 mmoles) in carbon tetrachloride (16 ml) was refluxed for 30 minutes on a water bath. After removal of a precipitate, the filtrate was washed with a sodium hydrogensulfite solution and water and dried over sodium sulfate. The evaporated residue was recrystallized from ethanol to give 3-(2-bromo-1-methylethenyl)tropolone [**5a** (1.20 g, 60%), **5b** (920 mg, 55%)] from **la,b** and 7-bromo-5-isopropyl-3-methyl-8*H*-cyclohepta[*b*]furan-8-one (**3c**) (490 mg, 35%) and 3-(2-bromo-1-methylethenyl)-5-isopropyl-tropolone (**5c**) (195 mg, 11%)] from **lc**, respectively.

5,7-Dibromo-3-(2-bromo-1-methylethenyl)tropolone (5a).

This compound was obtained as yellow needles, mp 164-165°; ir (potassium bromide): ν max 3185 (OH), 1610 cm⁻¹ (C=0); ¹H nmr (deuteriochloroform): δ 2.11 [3H, s, 3-C(CH₃)], 6.37 (1H, m, = CH_z), 7.67 (1H, d, J = 1.6 Hz, H-4), 8.32 (1H, d, J = 1.6 Hz, H-6).

Anal. Calcd. for $C_{10}H_7O_2Br_3$: C, 30.11; H, 1.77. Found: C, 30.24; H, 1.82.

7-Bromo-5-methyl-3-(2-bromo-1-methylethenyl)tropolone (5b).

This compound was obtained as yellow micro-needles, mp 104-106°; ir (chloroform): ν max 3140 (OH), 1610 cm⁻¹ (C=O); ¹H nmr (deuteriochloroform): δ 2.12 [3H, d, J = 1.8 Hz, 3-C(CH₃)], 2.43 (3H, s, 5-CH₃), 6.29 (1H, m, = CH₂), 7.23 (1H, brd, J = 2.0 Hz, H-4), 7.29 (1H, brd, J = 2.0 Hz, H-6).

Anal. Calcd. for $C_{11}H_{10}O_2Br_2$: C, 39.55; H, 3.02. Found: C, 39.85; H, 3.00.

7-Bromo-5-isopropyl-3-(2-bromo-1-methylethenyl)tropolone (5c).

This compound was obtained as yellow needles, mp 139-140°; ir (chloroform): ν max 3140 (OH), 1605 cm⁻¹ (C=O); ¹H nmr (deuteriochloroform): δ 1.27 [6H, d, J = 7.0 Hz, 5-C(CH₃)_z], 2.13 (3H, brs, 3-C(CH₃)], 2.82 (1H, sept, J = 7.0 Hz, 5-CH), 6.31 (1H, m, = CH_z), 7.27 (1H, d, J = 1.8 Hz, H-4), 7.90 (1H, brd, J = 1.8 Hz, H-6).

Anal. Calcd. for $C_{13}H_{14}O_2Br_2$: C, 43.21; H, 3.90. Found: C, 43.21; H, 4.02.

Cyclization of 3-(2-Bromo-1-methylethenyl)tropolones 5a-c.

General Procedure.

A solution of 3-(2-bromo-1-methylethenyl)tropolones **5a-c** (0.1 mmole) in carbon tetrachloride (5 ml) was refluxed for 3 hours in the presence of potassium carbonate (14 mg, 0.1 mmole). After filtration of the carbonate, the filtrate was evaporated to dryness and recrystallized from ethanol to give the 8*H*-cyclohepta[*b*]-furan-8-one [**3a** (28 mg, 87%), **3b** (21 mg, 82%), **3c** (21 mg, 76%)].

Diazo-coupling Reaction of 3-Isopropenyltropolone (la).

General Procedure.

To a solution of 3-isopropenyltropolone (1a) (810 mg, 5 mmoles) in pyridine (10 ml) was added dropwise the arene-diazonium chloride solution, prepared from the substituted aniline (5.5 mmoles), with stirring under cooling with an ice-cooled bath. After stirring for 2 hours at the same temperature, the precipitate was collected and recrystallized from benzene to give 5-arylazo-3-isopropenyltropolones 6a-f.

3-Isopropenyl-5-phenylazotropolone (6a).

This compound was obtained as orange needles; yield 530 mg (40%), mp 142-143°; ir (potassium bromide): ν max 3175 (OH), 1605 cm⁻¹ (C=0); ¹H nmr (deuteriochloroform): δ 2.21 (3H, s, CH₃), 5.15 (1H, m, = CH_E), 5.30 (1H, m, = CH_Z), 7.2-8.3 (6H, m). Anal. Calcd. for C₁₆H₁₄N₂O₂: C, 72.16; H, 5.30; N, 10.52. Found: C, 72.18; H, 5.31; N, 10.24.

3-Isopropenyl-5-(4-methylphenylazo)tropolone (6b).

This compound was obtained as orange needles, yield 950 mg (68%); mp 152-153°; ir (potassium bromide): ν max 3195 (OH), 1614 cm⁻¹ (C=0); ¹H nmr (deuteriochloroform): δ 2.20 [3H, s, 3-C(CH₃), 2.40 (3H, s, 4'-CH₃), 5.13 (1H, m, = CH_E), 5.30 (1H, m, = CH_Z), 7.2-8.5 (7H, m).

Anal. Calcd for C₁₇H₁₆N₂O₂: C, 72.83; H, 5.75; N, 10.00. Found: C, 72.71; H, 5.93; N, 9.96.

3-Isopropenyl-5-(4-methoxyphenylazo)tropolone (6c).

This compound was obtained as orange needles, yield 830 mg (56%), mp 126-127°; ir (potassium bromide): ν max 3195 (OH), 1603 cm⁻¹ (C=0); ¹H nmr (deuteriochloroform): δ 2.25 (3H, s, CH₃), 3.90 (3H, s, OCH₃), 5.12 (1H, m, =CH_E), 5.29 (1H, m,

 $= CH_z$), 6.9-8.3 (7H, m).

Anal. Calcd. for $C_{17}H_{16}N_2O_3$: C, 68.90; H, 5.44; N, 9.46. Found: C, 68.90; H, 5.31; N, 9.39.

5-(4-Chlorophenylazo)-3-isopropenyltropolone (6d).

This compound was obtained as reddish orange needles, yield 920 mg (61%), mp 140-141°; ir (potassium bromide): ν max 3201 (OH), 1628 cm⁻¹ (C=0); 'H nmr (deuteriochloroform): δ 2.21 (3H, s, CH₃), 5.12 (1H, m, = CH_E), 5.28 (1H, m, = CH_Z), 7.31 (1H, d, J = 10.0 Hz, H-7), 7.41 (2H, dm, J = 8.0 Hz, H-3',4'), 7.75 (2H, dm, J = 8.0 Hz, H-2', 6'), 8.00 (1H, dd, J = 10.0, 2.0 Hz, H-4), 8.20 (1H, d, J = 2.0 Hz, H-6).

Anal. Calcd. for $C_{16}H_{13}N_2O_2Cl$: C, 63.90; H, 4.36; N, 9.32. Found: C, 63.90; H, 4.38; N, 9.39.

5-(4-Bromophenylazo)-3-isopropenyltropolone (6e).

This compound was obtained as raddish orange needles, yield 1.38 g (80%), mp 151-152°; ir (potassium bromide): ν max 3199 (OH), 1608 cm⁻¹ (C = 0); ¹H nmr (deuteriochloroform): δ 2.15 (3H, s, CH₃), 5.12 (1H, m, = CH_E), 5.29 1H, m, = CH_Z), 7.2-8.3 (7H, m). Anal. Calcd. for C₁₅H₁₃O₂Br₂: C, 55.67; H, 3.80; N, 8.12. Found: C, 55.76; H, 3.89; N, 8.13.

3-Isopropenyl-5-(4-nitrophenylazo)tropolone (6f).

This compound was obtained as orange red needles, yield 780 mg (50%), mp 170-171°; ir (potassium bromide): ν max 3107 (OH), 1609 cm⁻¹ (C=O); ¹H nmr (deuteriochloroform); δ 2.15 (3H, s, CH₃), 5.15 (1H, m, = CH_E), 5.30 (1H, m, = CH_Z), 7.2-8.4 (7H, m). Anal. Calcd. for C₁₆H₁₃N₃O₄: C, 61.73; H, 4.21; N, 13.50. Found: C, 61.44; H, 4.38; N, 13.56.

Reaction of 3-Isopropenyl-5-(4-methylphenylazo)tropolone (6b) with Bromine.

To an ice-cooled stirred solution of **5b** (280 mg, 1 mmole) in pyridine (6 ml) was added dropwise bromine (320 mg, 2 mmoles). After stirring for 2 hours, the reaction mixture was poured into water (10 ml). A yellow precipitate was collected and recrystallized from benzene to give 7-bromo-3-methyl-5-(4-methylphenylazo)-8*H*-cyclohepta[*b*]furan-8-one (7) as yellowish orange crystals, yield 170 mg (49%), mp 232-233°; ir (potassium bromide): ν max 1658 cm⁻¹ (C=0); ¹H nmr (deuteriochloroform): δ 2.50 (3H, s, CH₃), 2.61 (3H, s, CH₃), 7.42 (2H, dm, J = 8.0 Hz, H-3',5'), 7.81 (1H, s, H-2), 8.01 (2H, dm, J = 8.0 Hz, H-2',6'), 8.32 (1H, d, J = 1.8 Hz, H-6), 9.21 (1H, d, J = 1.8 Hz, H-4).

Anal. Calcd. for $C_{17}H_{13}N_2O_2Br$: C, 57.16; H, 3.67; N, 7.84. Found: C, 56.91; H, 3.73; N, 7.56.

REFERENCES AND NOTES

- [1] T. Nozoe, K. Takase, and H. Matsumura, "Dai Yuki Kagaku", M. Kotake, ed, Asakura Shoten, Tokyo, 1960, Vol 13, pp 1-437.
 - [2] F. Pietra, Chem. Rev., 73, 293 (1973).
- [3] D. Lloyd, "Non-benzenoid Conjugated Carbocyclic Compounds", Elsevier, Amsterdam, 1984, pp 107-125.
- [4] K. Takase, T. Kusunose, and T. Meguro, 12th National Meeting of the Chemical Society of Japan, 1959, (Ref [1], p 173).
- [5] K. Imafuku, K. Yamaguchi, and H. Matsumura, Bull. Chem. Soc. Japan., 53, 745 (1980).
 - [6] K. Imafuku and K. Arai, Synthesis, 501 (1989).
 - [7] G. Komppa, Ber., 28, 2968 (1893).
 - [8] R. Stromer and M. Simon, Liebigs Ann. Chem., 342, 1 (1905).