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(1) (a) This work was supported by Public Health Service Research Grant CA 12193 from the National Cancer Institute. (b) Acknowledgment is made to the National Science Foundation for funds for the purchase of the mass spectrometer used in this research.
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(15) Melting points and boiling points are uncorrected. Infrared spectra were taken on a Perkin-Elmer Model 457 infrared spectrophotometer. Ultraviolet spectra were taken on a Beckman DBGT recording spectrophotometer using 1-cm matched quartz cells. Nmr spectra were determined at 60 MHz with a Varian T-60 spectrometer. Signals are reported in parts per million (δ) downfield from internal tetramethylsilane. Mass spectra were obtained using a Hitachi Perkin-Elmer RMU-7L spectrometer. Microanalyses were obtained by Atlantic Microlab, Inc., Atlanta, Ga. Gas-liquid chromatography was carried out using a Perkin-Elmer 881 gas chromatograph. The following columns were used: A (6 ft × 0.125 in., 10% Carbowax K-20M on Chromosorb W); B (6 ft × 0.125 in., 10% SE-30 on Chromosorb W).
(16) The uv and ir spectra of **6** were essentially identical with those reported by Büchi and coworkers (ref 7).

Synthesis of Furano Steroids and Analogs *via* Claisen Rearrangement

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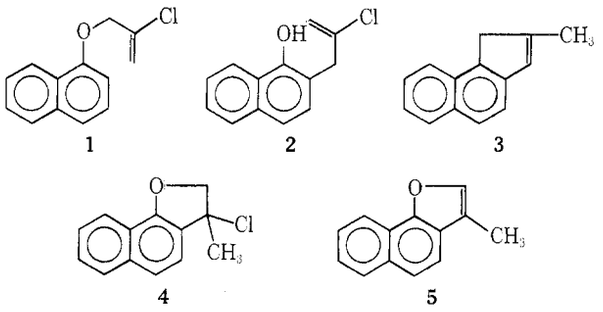
Interest in fused oxa steroids and related systems is evidenced by the variety of synthetic approaches[1] described in the recent literature. We report here the preparation of such compounds through a convenient route based on the work of Hurd and Webb.[2]

Commercially available 2,3-dichropropene-1 was used to alkylate an appropriate phenol and the resulting ether was rearranged by heating in *N,N*-dimethylaniline. Of the two compounds formed the major product was a chlorine-containing phenol derivative which could be cyclized in good yield to the minor product under the influence of a strong acid. The structure of the various compounds could be easily deduced from their pmr spectra.

Thus, the α-naphthol ether **1** produced a phenol **2** and a furanonaphthalene which could be separated on a neutral-alumina column. Two alternative structures **3** and **5** appeared reasonable for the furanonaphthalene, the former arising from the Claisen rearrangement product **2** and the latter *via* a possible intermediate such as **4**.

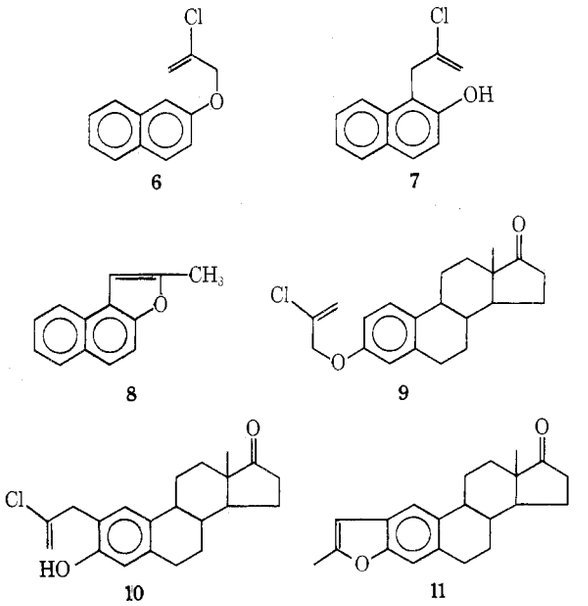


1 2 3 4 5

Extensive studies[3] on the pmr spectra of furan compounds have shown that α protons resonate at about τ 2.5 and β protons at about τ 3.5. A one-proton singlet at τ 3.6 in the pmr spectrum of the minor product from the rearrangement of **1** clearly indicated **3** to be the correct structure. The picrate of this compound had the same melting point as that recorded by Wilds and Johnson[4] for the picrate of **3** prepared by a different method. The intermediacy of a propynyl naphthyl ether in this rearrangement is excluded because such an ether cyclizes to a naphthopyran.[5]

The formation of the minor product **3** in good yield when **2** was treated with polyphosphoric acid is in accord with the assigned structure because the acid hydrolysis of the vinyl chloride would generate an acetyl function. It was observed that heating of the phenolic product **2** (or **7**) for a long period (10–14 hr) at a higher temperature (250°) failed to produce any significant amount of **3** (or **8**).

The allyl ether **6** from β-naphthol gave the rearrangement products **7** and **8**. The structure of the furano compound was again based on pmr spectra and identity of melting point of the picrate with that recorded for the picrate of **8** in the literature.[6]



6 7 8 9 10 11

The β-chloro allyl ether **9** from estrone gave a phenol **10** on rearrangement. The pmr spectrum of this compound showed the presence of two p protons; therefore, the allyl group had migrated to C-2 rather than to C-4. Treatment of the phenol **10** with polyphosphoric acid led to the furano steroid **11** in poor yield; cold sulfuric acid (90%), which proved to be a better cyclizing agent, produced **11** in 15% yield. The single-proton signal at τ 3.6 in the pmr of **11** is in

agreement with the β-unsubstituted furan structure assigned.

Experimental Section[7]

2-Chloro-2-propenyl α-Naphthyl Ether (1). A mixture of α-naphthol (5 g), anhydrous potassium carbonate (20 g), potassium iodide (2 g), and 2,3-dichloropropene (15 ml) in dry acetone (250 ml) was heated under reflux for 24 hr. The reaction mixture was filtered and the filtrate was evaporated. The residue was purified by column chromatography to give 6.3 g (90%) of **1**: ir 3030 (=CH_2), 660, 650, and 630 cm^{-1} (=CCl); nmr ($CDCl_3$) τ 1.6–2.9 (7 H, m, aromatic H), 4.5 (2 H, d, ClC=CH_2), 5.4 (2 H, s, -OCH_2=CCl-).

Anal. Calcd for $C_{13}H_{11}OCl$: C, 71.40; H, 5.07. Found: C, 71.20; H, 5.00.

Claisen Rearrangement of 1. The allyl ether **1** (2.5 g) was heated with *N,N*-dimethylaniline (4 ml) at 193° under nitrogen for 2 hr. The resulting solution was shaken with ice and dilute hydrochloric acid and extracted with chloroform. Upon evaporation the organic layer gave a mixture of two components (tlc) which were separated on an alumina column using petroleum ether (bp 40–60°) as the eluent. The first fraction was the neutral compound **3**: 0.16 g (6%); mp 21°; picrate (orange needles) mp 113° (lit.[4] mp 113–115°); ir 1620 (aromatic), 820 (trisubstituted double bond), 740 and 680 cm^{-1} (aromatic); nmr ($CDCl_3$) τ 1.6–3.0 (6 H, m, aromatic H), 3.6 (1 H, s, β-H of furan), 7.5 (3 H, s, CH_3).

Anal. Calcd for $C_{13}H_{10}O$: C, 85.69; H, 5.53. Found: C, 85.42; H, 5.50.

The second fraction, which was the major component, was the phenolic product **2**: 2.1 g (84%); mp 53°; ir 3350–3200 (-OH), 3030 (C=CH_2), 885 (C=CH_2), 610, 650, 660 cm^{-1} (-ClC=C-); nmr ($CDCl_3$) τ 1.5–2.8 (6 H, m, aromatic H), 4.7 (2 H, d, H_2C=CH-), 5.5 (1 H, broad, -OH), 5.9 (2 H, s, -CH_2-).

Anal. Calcd for $C_{13}H_{11}OCl$: C, 71.40; H, 5.07. Found: C, 71.52; H, 5.3.

Cyclization of 2. To polyphosphoric acid (prepared by adding 5 g of P_2O_5 to 3 ml of orthophosporic acid) was added **2** (0.5 g) with continuous stirring and heating on a water bath. After about 30 min the reaction mixture was decomposed with cold water and extracted with chloroform. The organic layer was stripped of solvent and the residue was purified by chromatography over alumina; elution with petroleum ether (bp 40–60°) gave a compound (0.3 g, 70%) identical in all respects with the minor fraction (**3**) obtained in the Claisen rearrangement experiment.

2-Chloro-2-propenyl β-Naphthyl Ether (6). Using the same procedure as for the preparation of **1**, there was obtained in 90% yield the title compound: mp 38°; ir 3030 (-C=CH_2), 885–895 (C=CH_2), 625, 690 cm^{-1} (-C=CCl); nmr ($CDCl_3$) τ 0.0–3.0 (7 H, m, aromatic H), 4.5 (2 H, d, -ClCl=CH_2), 5.4 (2 H, broad s, -CH_2O-).

Anal. Calcd for $C_{13}H_{11}OCl$: C, 71.40; H, 5.07. Found: C, 71.25; H, 5.15.

Claisen Rearrangement of 6. The same procedure as before was used. The first compound (minor component) off the neutral alumina column was **8** (yield 7%): mp 52° (lit. mp 56–57°); picrate (orange red crystals) mp 141° (lit. mp 140°); ir 805 cm^{-1} (>C=CH-); nmr ($CDCl_3$) τ 1.5–2.7 (6 H, m, aromatic H), 3.3 (1 H, s, β-H of furan), 7.5 (3 H, s, CH_3).

Anal. Calcd for $C_{13}H_{10}O$: C, 85.69; H, 5.53. Found: C, 85.45; H, 5.45.

The second fraction (major component) corresponded to **7** (yield 87%): ir 3500–3250 (OH), 3030, 1650, and 890 (-CH=CH_2), 690, 660, 610 cm^{-1} (-CCl=C<); nmr ($CDCl_3$) τ 2.0–3.2 (6 H, m, aromatic H), 5.05 (2 H, d, -CCl=CH_2), 5.90 (2 H, s, -CH_2CCl=).

Anal. Calcd for $C_{13}H_{11}OCl$: C, 71.40; H, 5.07. Found: C, 71.15; H, 5.00.

Cyclization of 7. Cyclization with PPA as in the experiment with **2** converted **7** (0.35 g) to **8**, mp 51–52°, picrate (orange red needles) mp 139–140°; the yield was 75%.

2-Chloro-2-propenyl Ether of3-Hydroxy-1,3,5(10)-estratrien-17-one (9). A mixture of estrone (2 g), anhydrous potassium carbonate (20 g), potassium iodide (2 g), 2,3-dichloropropene (4 ml), and dry acetone (200 ml) was heated under reflux for about 25 hr. The reaction mixture was filtered and the filtrate was stripped of solvent to give a residue which after purification by chromatography over alumina amounted to 2.1 g (80%) of **9**: mp 107–108°; ir 1740 (CO), 920, 900, 880 (C=CH_2), 670, 650 cm^{-1} (-CCl=C<); nmr ($CDCl_3$) τ 2.6–3.4 (3 H, m, aromatic H), 4.5 (2 H, d, -ClC=CH_2), 5.4 (2 H, broad s, -CH_2CCl=), 9.1 (3 H, s, 18-CH_3).

Anal. Calcd for $C_{21}H_{25}O_2Cl$: C, 73.13; H, 7.30. Found: C, 72.95; H, 7.13.

Claisen Rearrangement of 9. The allyl ether **9** (1 g) was dissolved in *N,N*-dimethylaniline (3 ml) and heated to 193° in an oil bath under nitrogen for 4 hr. A single product (0.6 g, 60%) was obtained after chromatography which was identified as **10**: mp 203°; ir 3300–3400 (OH), 1740 (CO), 890 (>C=CH_2), 710 cm^{-1} (>C=CCl-); nmr ($CDCl_3$) τ 2.9 (1 H, broad s, aromatic H), 3.5 (1 H, broad s, aromatic H), 4.8 (2 H, d, CH_2=CCl-), 6.35 (2 H, broad s, -CH_2CCl=), 9.10 (3 H, s, 18-CH_3); mass spectrum *m/e* (rel intensity) 346 (1, M^+), 344 (3, M^+).

Anal. Calcd for $C_{21}H_{25}O_2Cl$: C, 73.13; H, 7.30. Found: C, 73.05; H, 7.45.

17-Keto-5′-methylestra-1(10),4-dieno[3,2-*c*]furan (11). Cyclization of **10** (0.5 g) was carried out by stirring with 90% sulfuric acid (4 ml) for 30 min at 0°. The reaction mixture was decomposed with ice water and extracted with chloroform. After the organic layer was stripped of solvent and the residue was purified by preparative tlc (solvent system chloroform–benzene, 70:30), there was obtained 70 mg (15%) of the title compound: mp 155–158°; nmr ($CDCl_3$) τ 2.7 (2 H, 2 broad s, aromatic H), 3.6 (1 H, s, β-H of furan), 7.5 (3 H, s, CH_3 on furan ring), 9.0 (3 H, s, 18-CH_3); mass spectrum *m/e* 308 (M^+).

Anal. Calcd for $C_{21}H_{24}O_2$: C, 81.78; H, 7.84. Found: C, 81.85; H, 7.53.

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Registry No.—**1**, 51911-83-2; **2**, 51911-84-3; **3**, 25826-63-5; **3** picrate, 51911-85-4; **6**, 51911-86-5; **7**, 51911-87-6; **8**, 18747-04-1; **8** picrate, 51911-88-7; **9**, 51933-35-8; **10**, 51933-36-9; **11**, 51933-37-0; α-naphthol, 90-15-3; 2,3-dichloropropene, 78-88-6; β-naphthol, 135-19-3; estrone, 53-16-7.

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