

Synthesis of 1,6-Didehydro[10]annulene. Observation of Its Exceptionally Facile Rearrangement To Form the Biradical 1,5-Dehydronaphthalene

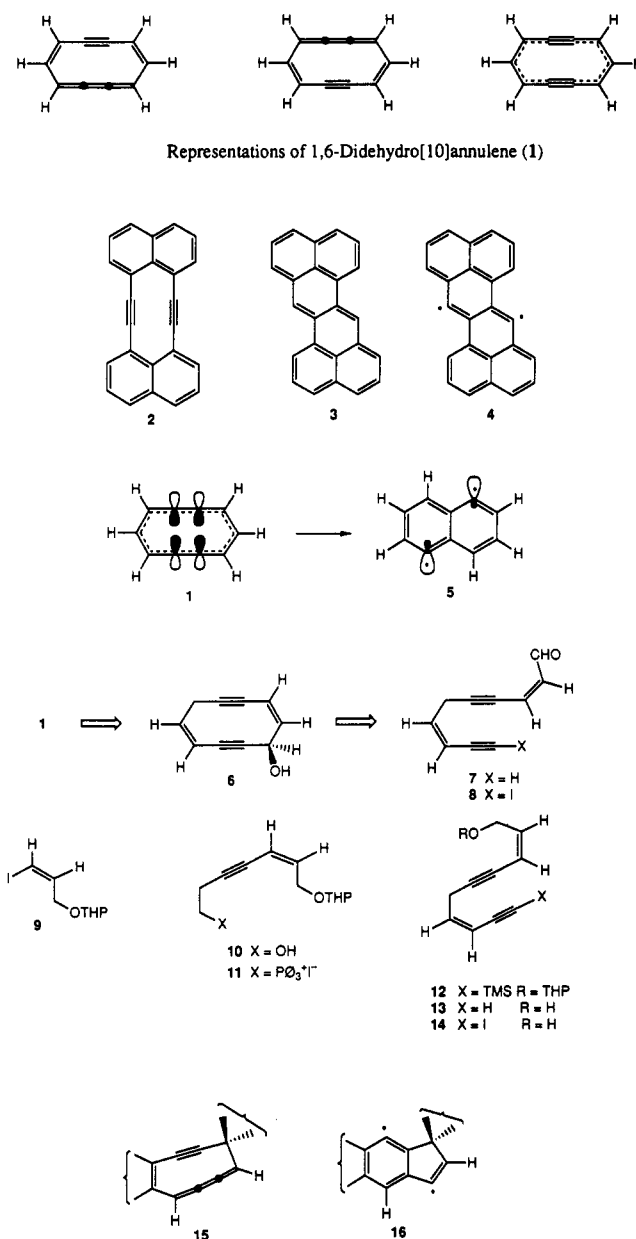
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1,6-Didehydro[10]annulene (**1**) has been recognized as an intriguing organic molecule for more than 40 years.¹ Notwithstanding its structural simplicity and nominal aromaticity, neither the parent hydrocarbon nor any derivative of this C₁₀H₆ isomer has been prepared to date, although several laboratories have described efforts toward this end.^{2,3} Notable among these are the contributions of Sondheimer et al.^{2a,c,e} and Staab et al.^{2b,f} directed toward the synthesis of the hydrocarbon **2**. Though the latter molecule does not formally represent a derivative of **1**, it is nevertheless of considerable interest in the present context that all attempts to produce this substance led not to **2**, but instead to the hydrocarbon zethrene (**3**), a result which led the Sondheimer and Staab groups to invoke explicitly the biradical **4** via the proposed intermediate **2**.^{2e,f} In retrospect, this hypothesis presages much of the biradical-forming cycloaromatization chemistry to follow in later years,⁴ although it should be noted that the putative hydrocarbon **2** was never observed and that the conditions of these experiments (copper salts, pyridine reflux) allow for alternative interpretations of the data. We were drawn to consider the hydrocarbon **1** in light of its potential thermal conversion to the biradical 1,5-dehydronaphthalene (**5**), a reactive intermediate of considerable interest in its own right.⁵ In this communication we describe the first preparation of **1** and document its exceptionally facile conversion to 1,5-dehydronaphthalene (**5**) (Chart I).

Acetylenic alcohol **6** was chosen as the immediate synthetic precursor to **1** in view of the presumed facility of both the dehydration reaction that would transform **6** to **1** and the intramolecular acetylide-aldehyde addition reaction of substrate **7**, envisioned to provide **6**. However, all attempts to cyclize **7** via a metal acetylide intermediate met with failure, a result attributed to the extreme base sensitivity of **7** and, as later discovered, of **6** as well. Chromium(II)-mediated reaction of the iodo aldehyde

Chart I



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8, in contrast, proved to be an effective closure method;⁶ the iodo aldehyde cyclization precursor was synthesized as follows. (Z)-Vinyl iodide **9**⁷ was coupled with 3-buten-1-ol in tetrahydrofuran (THF) at 23 °C ((Ph₃P)₂PdCl₂, CuI, Et₃N) to afford the (Z)-enynone **10** in 79% yield.⁸ Transformation of **10** to the corresponding mesylate,⁹ the resultant mesylate to the iodide (LiI, THF, 55 °C), and finally the iodide to the phosphonium salt **11** (1.0 equiv of triphenylphosphine, acetonitrile, 80 °C) proceeded smoothly in 68% yield. Wittig reaction of the ylide derived from **11** (1 equiv of *n*-butyllithium with (trimethylsilyl)propionaldehyde (1.02 equiv) in THF at -78 °C provided the bis-enyne **12** (71%) as a 4.3:1 mixture of *Z* and *E* isomers at the newly-formed olefinic bond, respectively. Sequential deprotection of functional groups

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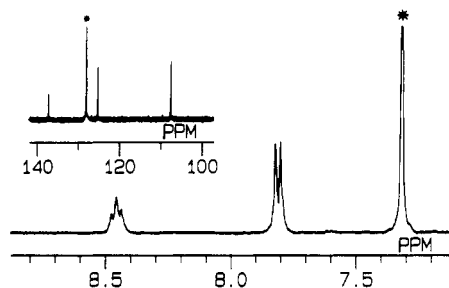


Figure 1. ^1H NMR spectrum of **1** (2:1 THF- d_6 /CD $_2$ Cl $_2$, -75 °C, 400 MHz): δ 8.45 (t, 2 H, J = 8.3 Hz, H5 and H10), 7.81 (d, 4 H, J = 8.3 Hz, H1, H4, H6, H9). Inset: ^{13}C NMR spectrum of **1** (CD $_2$ Cl $_2$, -90 °C, ^1H -decoupled, 100 MHz): δ 137.1 (2 C, C5, and C10), 125.1 (4 C, C2, C3, C7, and C8), 107.5 (4 C, C1, C4, C6, and C9). Assignments verified by selective ^1H -decoupled ^{13}C NMR.

within **12** (trichloroacetic acid, acetonitrile-water, 23 °C, THPO \rightarrow HO, 88%; triethylamine trihydrofluoride, methanol, 55 °C, TMSC \equiv C \rightarrow HC \equiv C, 97%) then afforded **13**. Iodination of **13** to form **14** was readily achieved by the method of Hofmeister et al. employing *N*-iodosuccinimide (1.02 equiv) and silver nitrate (0.1 equiv) in acetone (0–23 °C, 81%).¹⁰ Oxidation of **14** with the Dess–Martin periodinane (2.5 equiv, dichloromethane, 23 °C) provided the iodo aldehyde **8** in 85% yield.¹¹ Treatment of a dilute solution of **8** in rigorously deoxygenated THF at 0 °C with chromium(II) chloride (2.5 equiv) doped with nickel(II) chloride (0.01%) for 3 h afforded the cyclization product **6** in 40% yield after purification by flash column chromatography.⁶ Due to the extreme sensitivity of **6** toward adventitious decomposition when neat, this product was typically handled in solution in the presence of a free radical inhibitor.

Initial studies designed to transform **6** to **1** via the corresponding mesylate⁹ established that **1** has no appreciable lifetime above -40 °C. For example, treatment of **6** with methanesulfonic anhydride and triethylamine in deoxygenated THF- d_6 at -40 °C led to slow disappearance of the starting material with concomitant formation of 1,5-dideuterionaphthalene (^1H NMR analysis, $t_{1/2} \approx 1.5$ h); signals attributable to the presumed intermediate mesylate or to **1** were not observed, leading to the conclusion that mesylate formation is rate-determining and that cyclization of **1** to the biradical **5** is rapid at -40 °C. By contrast, variable-temperature NMR analysis of the reaction of **6** with trifluoromethanesulfonic anhydride and triethylamine at -90 °C showed clean and rapid conversion of **6** to a product assigned as **1**. ^1H and ^{13}C NMR data (Figure 1) are consistent with static or time-averaged D_{2h} symmetry for **1** at -90 °C. The proton-decoupled ^{13}C NMR spectrum consists of three singlets whose chemical shifts are approximated by averaging the anticipated chemical shifts for corresponding carbons in the two canonical resonance structures. The ^1H NMR chemical shifts show clear evidence of a diamagnetic ring current, supporting the notion that **1** is an "aromatic" compound (Figure 1). Samples of **1** were stable for extended periods at -90 °C but at higher temperatures cyclized readily to form naphthalene (50–85% yield, varying with the medium). In deuterated solvents, incorporation of deuterium was evident at the 1 and 5 positions of naphthalene. The kinetics for the cyclization reaction was determined in CD $_2$ Cl $_2$ in the presence of 1,4-cyclohexadiene (0.6 M) and found to be first-order ($k = (4.6 \pm 0.9) \times 10^{-4} \text{ s}^{-1}$, $\Delta G^\ddagger = 16.3 \pm 0.1 \text{ kcal/mol}$, -51 ± 1 °C, 85% yield of naphthalene). Thus, the half-life for cyclization of **1** at -51 °C is ~ 25 min, making this the most rapid biradical-forming cycloaromatization yet reported. The next most rapid cyclization of which we are aware is that of the neocarzinostatin cumulene intermediate (**15** \rightarrow **16**, $t_{1/2} \approx 2$ h at -38 °C, $\Delta G^\ddagger = 18.0 \pm 0.1 \text{ kcal/mol}$).^{4d-f} With the assumption that both processes have negligible entropies of activation, the free energies of activation may be compared directly, leading to a 1.7 kcal/mol lower barrier

for cyclization of **1** versus **15**. This is an interesting and unexpected outcome because it would appear that **15** is the more strained molecule. It should be pointed out that the exceedingly facile cyclization of **1** to **5** does not argue against the aromatic stabilization of the former. The stability usually associated with an aromatic compound relates to a reaction pathway in which aromaticity is invariably lost in transition; in the case of **1**, aromaticity is not disrupted in the transformation to **5**.

In conclusion, it seems both reasonable and useful to classify the biradical-forming cycloaromatization reactions into two categories: those involving cycloaromatization to form a biradical syn about the newly-formed σ bond, of which the Bergman reaction^{4a-c} may be considered prototypical, and those involving cycloaromatization to form a biradical anti about the newly-formed σ bond,^{2e,f,4d-i} perhaps now best illustrated by the transformation of **1** to **5**. Though rigorous comparisons are not possible, it would appear that the latter class of cyclization is generally a more facile reaction. On the basis of ab initio calculations it has been suggested that this effect has its origin in the differences in in-plane π - π repulsion in the two systems, this being exacerbated in the former class and diminished in the latter.¹² Finally, with regard to the enediyne antibiotics, it will clearly be of interest to design a molecule which will undergo a transformation analogous to **1** \rightarrow **5** after an appropriate "chemical activation" step; perhaps such a molecule already exists in nature.

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Supplementary Material Available: Listings of IR and ^1H and ^{13}C NMR spectral data for **6** and synthetic precursors to **6** (4 pages). Ordering information is given on any current masthead page.

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High-Intensity, Argon Ion Laser-Jet Photochemistry. Reactions between Transient Species: The Addition of Diphenylcarbene to the Photoenol of 2-Methylbenzophenone

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In principle, reactions between short-lived photochemical transients, transient-transient reactions, offer many possibilities for novel chemistry. Transient-transient reactions between identical species, such as radical coupling, are well-known, and while their efficiencies are enhanced at higher light intensities, they can frequently be observed at lower light levels in the absence of competing processes.¹ In contrast, very few examples of

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