Cyclophanes. 9.[1] *anti*-[2.2](2,6)Azulenophane. Synthesis and Charge-Transfer Interaction[2,3]

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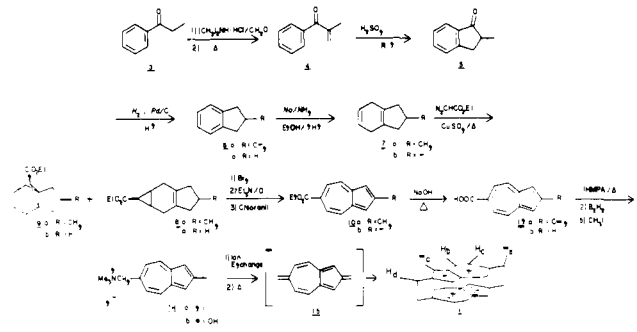
Abstract: The synthesis of a novel azulene containing phane, *anti*-[2.2](2,6)azulenophane (**1**), is described, It is prepared by the Hofmann pyrolysis of *N*-(2-methyl-6-azulyl)-*N,N,N*-trimethylammonium hydroxide (**14b**) in 4.3% yield along with polymer, 29%, 2,6-dimethylazulene (**16**), 1.1%, and 2-hydroxymethyl-6-methylazulene (**17**), 12%. *syn*-[2.2](2,6)Azulenophane (**2**) is not generated in the reaction. The quaternary ammonium salt used for pyrolysis is synthesized from propiophenone (**3**) in 13 steps. The azulene skeleton is constructed in good yield by a modification of the Buchner reaction. This modification, which seems general for the construction of substituted azulene nuclei, involves the addition of a carbene to a 4,7-dihydroindan system instead of the less reactive indan ring system. The addition occurs predominantly at the external rather than the internal double bond of the 4,7-dihydroindan ring. Charge-transfer interaction between the two azulene nuclei in **1** is indicated but is not a certainty from its electronic spectrum, where the longest wavelength band tails out to about 900 nm. Mono- and diprotonated forms are spectroscopically observed when **1** is treated with trifluoroacetic acid. The monoprotonated form exhibits a charge-transfer band in its electronic spectrum indicative of transannular charge-transfer interaction between the protonated and unprotonated azulene rings. In the diprotonated form there is no charge-transfer band consistent with the repulsive nature of the two protonated azulene nuclei. When compared with 2,6-dimethylazulene, **1** is a stronger π base toward protonation and reaction with tetracyanoethylene corroborating the π–π interaction between two azulene rings.

Intramolecular charge-transfer interaction in cyclophanes has been the subject of a number of studies by various research groups.[1,4] These studies have focused on the construction of phanes containing both donor and acceptor groups and on increasing the intramolecular interaction of these groups by adding electron-donating and electron-withdrawing functionality. Our interest in intramolecular charge-transfer processes led us to consider the potential interactions that azulene nuclei would have on one another intramolecularly.

Azulene has an unusually large dipole moment (1.0 D)[5] for a hydrocarbon and this physical property is used to give credence to the theory that the dipolar resonance form of azulene contributes heavily to the azulene hybrid (see Figure 1). If two azulene nuclei were rigidly positioned atop one another in a parallel fashion, attractive or repulsive interactions between the two ring systems could be expected to take place depending upon the orientation of dipoles of the two nuclei. Since the hydrocarbon bridges of symmetrically bridged [2.2]cyclophanes force a parallel orientation of the aromatic groups for maximum transannular interaction, we were intrigued by the kind of intramolecular interaction which might be generated in *anti*-[2.2](2,6)azulenophane (**1**) and *syn*-[2.2](2,6)azulenophane (**2**) (see Figure 2). The syn isomer would be expected to exhibit repulsive interactions between the rings. Perhaps owing to this repulsion the charge density of the dipolar resonance contributors of the rings would be reduced so that repulsion could be minimized. The repulsive forces between the two rings in **2** could conceivably preclude its formation. The anti isomer on the other hand would be expected to show attractive interaction between the azulene nuclei, perhaps of the charge-transfer type, and increase the charge density of the dipolar resonance contributors so that an enhanced attraction could be possible. This paper describes the synthesis of the anti isomer, **1**, by a method which potentially could have generated both **1** and **2**, and discusses some of the charge-transfer properties of this novel system.

Synthesis. The synthesis of the title compound is described in Scheme I. We chose a Hofmann pyrolytic route to **1** because we were interested in the sesquifulvalene-isomer intermediate, **15**, we expected would be generated during the pyrolysis and also because it would potentially allow for the synthesis of both **1** and **2** simultaneously. Thus, propiophenone (**3**) was treated under Mannich conditions[6] with dimethylamine hydrochloride

Scheme I



and paraformaldehyde followed by steam distillation in the presence of a catalytic amount of base affording α-methylenepropiophenone (**4**) in 66% yield. Cyclization of **4** in the presence of sulfuric acid gave 2-methyl-1-indanone (**5**)[6] quantitatively, which was catalytically reduced (95%) with hydrogen in the presence of acid to 2-methylindan (**6a**).[7] Birch reduction[8] of 2-methylindan afforded 4,7-dihydro-2-methylindan (**7a**) in 95% yield. Treatment of **7a** with ethyl diazoacetate[9] using copper sulfate as a catalyst gave a 75% yield of a mixture of carbene adducts **8a** and **9a** in a ratio of 4:1. These adducts were separated by fractional distillation and characterized spectrally. Ester **8a** was then consecutively treated with bromine, triethylamine, and chloranil without isolation of intermediates and afforded 2-methyl-6-carbethoxyazulene (**10a**) in 50% yield. Ester **10a** was unequivocally characterized in the next step when it was hydrolyzed to the known 2-methyl-6-carboxyazulene (**11a**)[10] in 95.5% yield.

It should perhaps be noted at this point that in our synthesis of **10a** the overall yield from 2-methylindan was 30%. In contrast, the method frequently chosen for the synthesis of azulenes is that of Buchner[10a] (ring expansion of indans) which gives yields that are ten times less. For instance, Plattner[10b] prepared a mixture of 5- and 6-carboxyazulenes and Reid[11] synthesized 5-methoxy-7-carboxyazulene by the Buchner method giving yields of crude product of 1 and 3%, respectively.

We considered that our method of first carrying out a Birch reduction on the indan and then adding the carbethoxycarbene to the reduced indan was an improvement on the Buchner

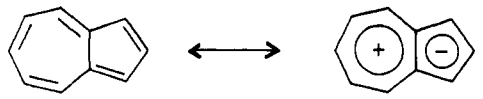


Figure 1.

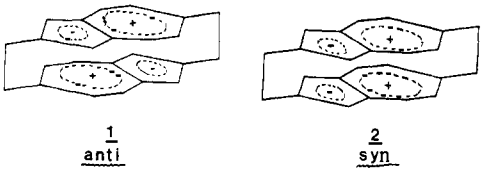


Figure 2.

synthesis (which adds the carbene to a less reactive aromatic ring) and might be a generally applicable route to substituted azulenes. (Of necessity our synthesis places a carbethoxy group in the 6 position, but this is not a hindrance since it can be removed by hydrolysis and decarboxylation.[11])

Our method was therefore applied to the synthesis of 6-carboxyazulene (**11b**) initially prepared by Plattner,[10b] No effort was made to optimize yields and each reaction was carried out only once. Indan (**6b**) was reduced under Birch conditions affording 4,7-dihydroindan (**7b**) in 90% yield. Dihydro **7b** was then treated with ethyl diazoacetate and copper sulfate catalysis giving 4-carbethoxytricyclo[5,3,0,$0^{3,5}$]decene-$\Delta^{1(7)}$ (**8b**) in 50% yield along with 20% of 10-carbethoxytricyclo[4.3.1,$0^{1,6}$]decene-Δ^{3} (**9b**). Again, preferential addition of the carbene occurred at the external double bond of the dihydroindan ring system as was observed in its reaction with **7a.** When **8b** was treated consecutively with bromine, triethylamine, and chloranil, 6-carbethoxyazulene (**10b**) was obtained in 30% yield and hydrolysis of a small sample afforded 6-carboxyazulene (**11b**), identical in all respects with authentic **11b.**[10b] The overall yield of acid **11b** from indan was 13.5% and this is to be contrasted with Plattner's result of 1% which was a mixture of carbethoxyazulene isomers,

Returning to our sequence for the preparation of **1,** acid **11a** was converted in 97% yield to the dimethylamide **12** by treatment with hexamethylphosphoric triamide (HMPT), Dimethylamide **12** was then reduced with diborane giving dimethylamine **13,** in 80% yield, which was characterized spectrally and by quantitative conversion with methyl iodide to quaternary ammonium iodide **14a.**

Iodide **14a** was then converted to the hydroxide salt **14b** by ion exchange over Amberlite IRA-400 and the aqueous solution of *N*-(2-methyl-6-azulyl)-*N,N,N*-trimethylammonium hydroxide (**14b**) was pyrolyzed in toluene in the presence of a radical inhibitor. Along with polymer (29%), the reaction afforded 2,6-dimethylazulene (**16,** 1.1%), 2-hydroxymethyl-6-methylazulene (**17,** 12%), and *anti*-[2,2](2,6)azulenophane (**1,** 4.3%). While there were at least five other colored components in the product mixture by thin layer chromatography, all in minor amounts, there was no indication that the syn isomer **2** was present. 2,6-Dimethylazulene (**16**) was characterized by spectral and melting point comparison with known material synthesized by borohydride reduction of iodide **14a.**[12] The structural assignment for 2-hydroxymethyl-6-methylazulene (**17**) was made spectrally (IR ($CHCl_3$) 3600 cm^{-1} (OH); NMR (CD_2Cl_2) δ 7.57 (AB q, 4 H, J = 10 Hz, 4, 5, 7, and 8 positions on azulene ring), 7.2 (s, 2 H, 1,3 positions on azulene ring), 5.0 (d, 2 H, $-OCH_2-$), 2.6 (s, 3 H, $-CH_3$), 2,1 (t, 1 H, -OH); UV-vis λ_{max} ($CHCl_3$) (log ϵ) 650 sh (2.03), 588 (2,50), 554 (2.51), 361 (3.16), 347 (3,60), 333 (3.64), 289 (4.80) 282 nm (4.76)) and by comparison with authentic 6-hydroxymethyl-2-methylazulene (IR $CHCl_3$) 3600 cm^{-1} (OH); NMR ($CDCl_3$) δ 7.54 (AB q, 4 H, J = 10 Hz, 4, 5, 7, and 8 positions on azulene ring), 7.08 (s, 2 H, 1, 3 positions on azulene ring),

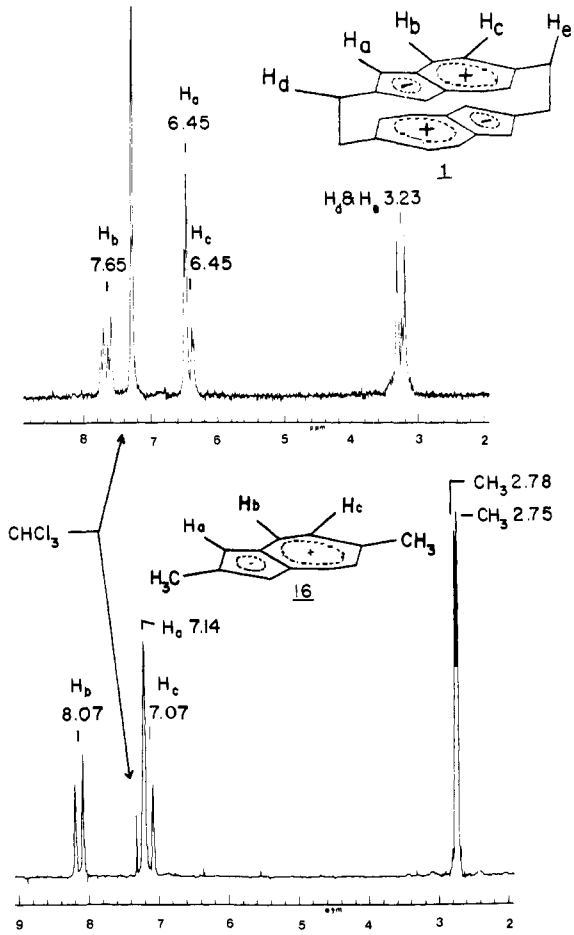


Figure 3. NMR spectra of *anti*-[2.2](2,6)azulenophane (**1**) (upper) and 2,6-dimethylazulene (**16**) (lower).

4.62 (s, 2 H, $-OCH_2-$), 2.56 (s, 3 H, $-CH_3$), 2.25 (bs, 1 H, -OH); UV-vis λ_{max} ($CHCl_3$) (log ϵ) 660 sh (1.90), 600 sh (2,37), 562 (2,44), 520 sh (2.30), 362 (3.08), 350 (3.70), 333 (3.60), 304 sh (3.78), 288 (4,85) 279 nm (4.77)) prepared by diborane reduction of **11a.** The spectral comparisons, especially the difference in chemical shift of the hydroxymethylene protons and the difference in the UV absorption pattern of the two compounds, led us to assign the hydroxymethyl substituent in the pyrolysis product to the 2 position of the azulene ring.

Characterization of *anti*-[2.2](2,6)Azulenophane (1). The azulenophane isolated from the pyrolysis reaction crystallized from $CHCl_3$ as blue-green, square plates and did not melt when heated up to 340 °C. The structural assignment for **1** is based on spectral evidence. The mass spectrum shows two prominent peaks; a molecular ion at *m/e* 308.155 (calcd for $C_{24}H_{20}$, *m/e* 308.156) and a base peak at *m/e* 154 associated with cleavage of the two ethylene bridges. This fragmentation pattern is normally observed in [2.2]phanes[13] and is consistent with either the syn or anti structure. The infrared spectrum is simple, showing absorptions at 3080–2850, 1568, and 1400 cm^{-1} characteristic of the azulene nuclei,[5]

The NMR spectrum of **1** is reproduced in Figure 3 along with that of **16** and is consistent with a cyclophane structure and the anti orientation of the azulene rings. The chemical shift for the a, b, and c protons of the azulene rings are found respectively at 0.69, 0.43, and 0.67 ppm upfield relative to those in 2,6-dimethylazulene. These upfield shifts are expected due to the position of protons relative to the shielding cone of the proximate azulene ring. the upfield shift of the a and c protons compares favorably with the 0.68 ppm upfield shift observed for the benzenoid protons in [2.2]paracyclophane relative to those of *p*-xylene.[14] The smaller upfield shift of the b protons

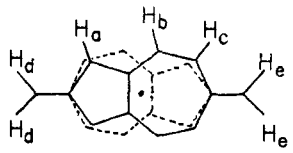


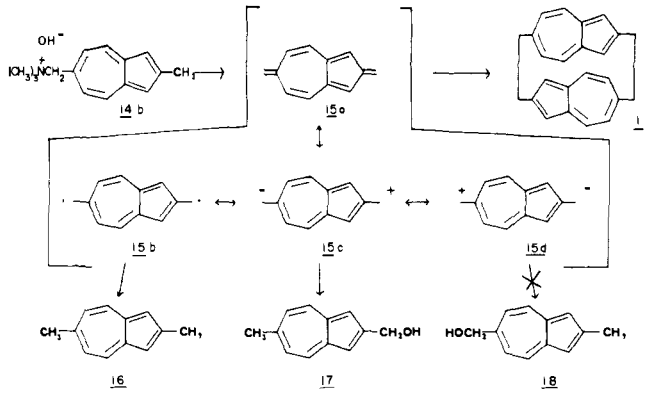
Figure 4. Anti orientation of **1**. For syn orientation rotate top azulene ring and two adjacent methylene groups by 180° around axis perpendicular to and passing through both azulene nuclei.

is characteristic of their being further removed from the shielding region of the proximate azulene ring (see Figure 4), and thus are shielded less than the a and c protons. This smaller upfield shift of the b relative to the a and c protons is consistent with the anti structure for **1** since the b protons in the syn isomer would be expected to exhibit similar upfield shifts as protons a and c due to their similar proximity to the shielding region of the neighboring azulene ring. In addition to the upfield shift exhibited for the azulenoid protons in **1** there is also observed a downfield shift of 0.53 ppm of the bridge d and e protons relative to the methyl protons in 2,6-dimethylazulene. The multiplicity of the absorption for these bridge protons also substantiates the anti orientation of the azulene rings in **1** since they would be expected to show an AA'BB' pattern. In contrast, the syn isomer should exhibit a singlet for each of the two equivalent sets of protons adjacent to the five- and seven-membered fused portions of the azulene rings. This is not observed.

Finally the electronic spectrum of **1** (see Figure 5) is consistent with a cyclophane structure and exhibits two broadened maxima, one in the visible region at λ_{max} ($CHCl_3$) 605 nm (ϵ 418) and the other in the ultraviolet region at λ_{max} ($CHCl_3$) 277 nm (ϵ 69 700). Similar to the electronic spectra of other [2.2]phanes[15] there is observed a general broadening of all bands in the spectrum and a bathochromic shift of 55 nm (normally 20–30 nm) of the long wavelength band relative to 2,6-dimethylazulene. This absorption band has a shoulder at 725 nm and a low ϵ absorption which tails out to 900 nm. This tailing may be indicative of charge-transfer interaction within **1**. The short wavelength band is hypsochromically shifted by 8 nm relative to that of 2,6-dimethylazulene and since it is a higher energy absorption is indicative of an attractive π–π interaction between the two azulene rings[15] suggesting an anti orientation.

In an attempt to substantiate our conclusion of the anti assignment efforts were made to determine the dipole moment of **1**. Compound **1** should have a zero moment while **2** should have a measurable moment. The determination, however, was hampered by the insolubility of **1** in nearly all solvents useful for determining dipole moments and because the maximum concentration obtainable in $CHCl_3$ is ca. 5×10^{-3} M, at least an order of magnitude less than what would be required for reliable dipole moment measurements.

Scheme II



X-Ray structure determination of **1** is proving difficult since it was found that the crystal was disordered ($P4_2/mnm$, Z = 2), a common feature in azulene crystal systems.

Mechanistic Discussion of the Hofmann Pyrolysis. Upon heating the quaternary salt **14b**, trimethylamine and water are eliminated and we believe that dimethide **15a** is generated in situ (see Scheme II). This represents a 1,8 Hofmann elimination of which there is one other recent example in the literature.[16] The intermediate can be represented by a number of resonance forms like diradical **15b** or dipolar forms **15c** and **15d**.

It should be noted that resonance form **15c** should be stabilized by the intrinsic polarity of the azulene ring system, which places the partial positive charge in the seven-membered ring adjacent to the partial negative charge on the substituent in the 6 position and the partial negative charge in the five-membered ring adjacent to the partial positive charge on the substituent in the 2 position. The polarity of the azulene ring system similarly destabilizes resonance form **15d** since like charges are adjacent.

In this type of reaction cyclophanes are formed by the cycloaddition of two molecules of intermediate dimethide. There is evidence that this cycloaddition is a diradical process.[17] Since the reaction is thermal and 4n π electrons are involved it cannot be concerted as defined by Woodward and Hofmann,[18] Thus for azulenophane, the intermediate dimethide requires a 1,8-cycloaddition of which there has been only one other example in cyclophane synthesis.[16] All other cyclophanes formed

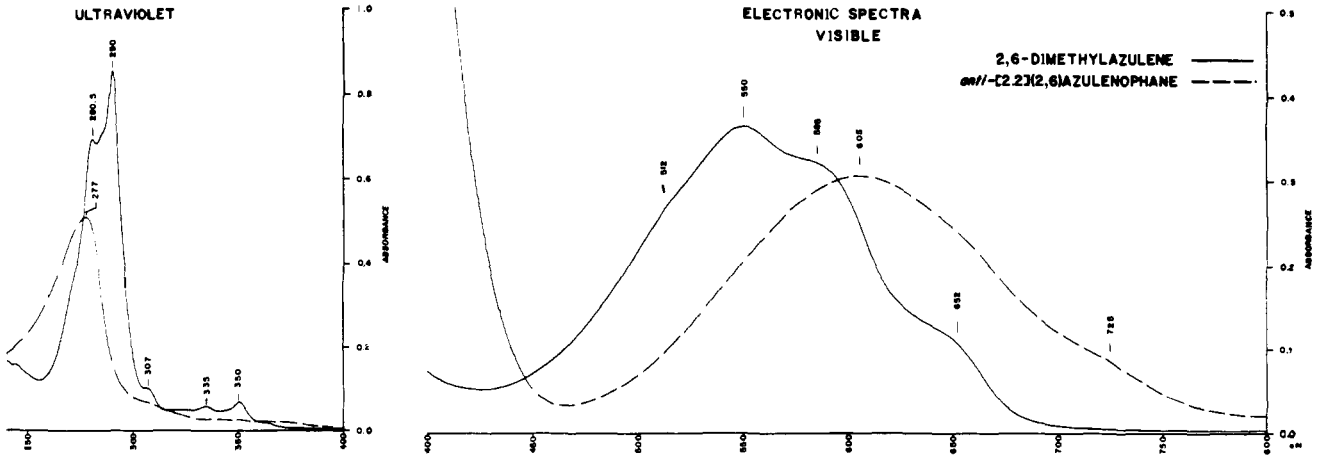
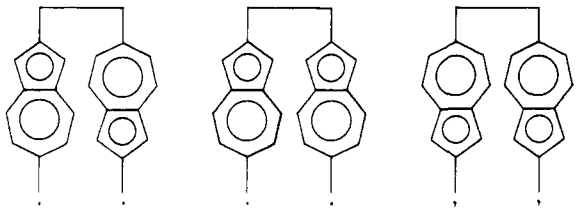


Figure 5. Ultraviolet and visible spectra of *anti*-[2.2](2,6)azulenophane (**1**) and 2,6-dimethylazulene (**16**) in chloroform. (Note the tailing of the long wavelength band which reaches baseline at about 900 nm in **1**).



19 20 21

Figure 6.

Table I

Acceptor	λ_{max}, nm	Acceptor	λ_{max}, nm
Iodine	408	2,3-Dicyanobenzo-quinone	641
Trinitrobenzene	458	Chloranil	645
2,4,7-Trinitrofluoreno-ne	535	Tetracyanoethyle-ne	740

by the Hofmann pyrolysis method have been by 1,6-cycloadditions.

In the dimerization process it is necessary for the planes of the π systems of the two dimethide units to become parallel, before the bond formation of both bridges of the cyclophane is complete. Since azulene is not totally symmetric after one of the bridging bonds is formed three U-shaped diradicals are possible, **19, 20,** and **21.**

Dimer **19** should be stabilized by the favorable dipole interactions of the two azulene ring systems and **20** and **21** should be destabilized by the same effect. Because of the favorable dipole interaction in **19** one might expect *anti*-**1** to be formed preferentially over *syn*-**2.** Because of unfavorable interaction **20** and **21** might prefer a flat linear form from which polymerization is likely. Before the second bridging bond is formed, **19** can also react with another molecule of dimethide, forming a trimer and then a tetramer, etc,, until polymer precipitates from the reaction mixture. To minimize polymer formation high-dilution techniques were employed along with the addition of radical inhibitors.

The other two products which were isolated in the pyrolysis can also originate from the intermediate dimethide. While hydrogen abstraction from solvent gives **16,** addition of H_2O gives **17.** Theoretically the addition of H_2O can occur in two ways to form either **17** or **18.** In actuality no **18** was formed,

An explanation may be found in the intrinsic polarity of the azulene ring system which should make **15c** a more important contributor than **15d** in the total resonance hybrid. The fact that **17** is the major monomeric product formed in the pyrolysis of **14b** strongly supports the above hypothesis. Contributor **15c** can also explain the formation of only the anti isomer of azulenophane, since dimerization of **15c** is more likely to occur when the azulene rings are parallel in an anti orientation.

Charge-Transfer Interactions. In charge-transfer complexes azulene normally acts as a π donor. It forms charge-transfer complexes with many acceptors (π acids).[19] Table I lists some of the acceptors in charge-transfer complexes with azulene and their wavelength (λ_{max}) of absorption,

Our synthesis of azulenophane **1** was initiated on the premise that intramolecular charge transfer might exist between two azulene nuclei. It was difficult, however, to definitely attribute the long-wavelength tail in the visible spectrum of **1** to charge-transfer interaction, though the position, breadth, and intensity of the absorption is typical of what is found for intramolecular complexation.[1,4d,e] Interesting charge-transfer effects were, however, observed in **1** as it underwent protonation.

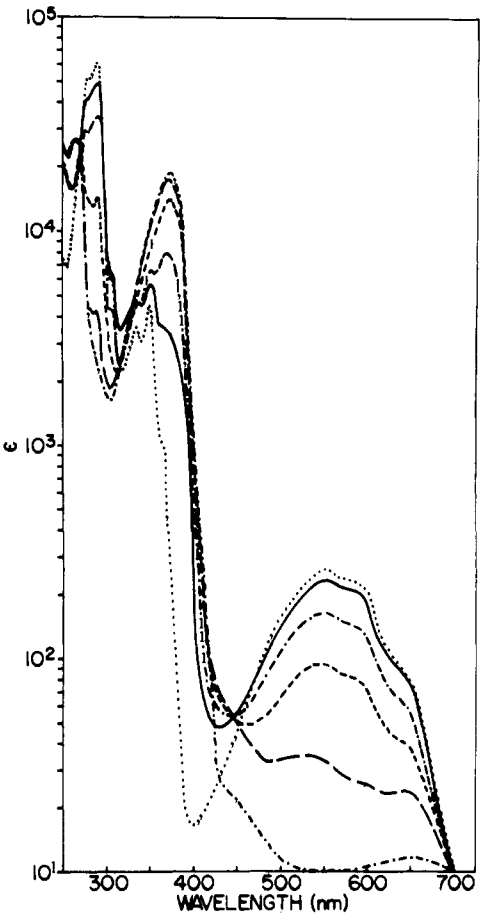
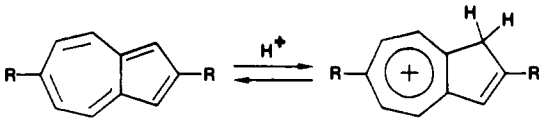


Figure 7. Electronic spectra of 2,6-dimethylazulene (**16**) in chloroform and in various concentrations of trifluoroacetic acid (TFA): (·····) in $CHCl_3$; (—) in 0.135 M TFA; (·····) in 0.170 M TFA; (- - - - - - - -) in 0.20 M TFA; (— — — — —) in 0.27 M TFA; (·····) in 2.02 M TFA.

Scheme III



22 R = H 23 R = H

16 R = CH_3 24 R = CH_3

It is known that azulenes protonate in the 1 position to give a substituted tropylium (see Scheme III), The ring system possesses a formal positive charge and the characteristic blue color of azulene changes to pale yellow. For the azulenium ion itself the longest wavelength and most intense band is at 370 nm[5] in its electronic spectrum. We considered that protonation of one azulene ring in **1** would create a better opportunity for stronger interaction with the second unprotonated azulene ring.

Solutions of *anti*-**1** were prepared in chloroform containing various concentrations of trifluoroacetic acid (TFA) and their electronic spectra were recorded, For comparison, 2,6-dimethylazulene was treated similarly, The spectra are shown in Figures 7, 8, and 9 and clearly demonstrate the existence of charge-transfer interactions in the monoprotonated azulenephane,

The model compound, 2,6-dimethylazulene (**16**), behaves as expected for an azulene moiety. With increasing acid concentration the visible band centered at 550 nm and the ultra-

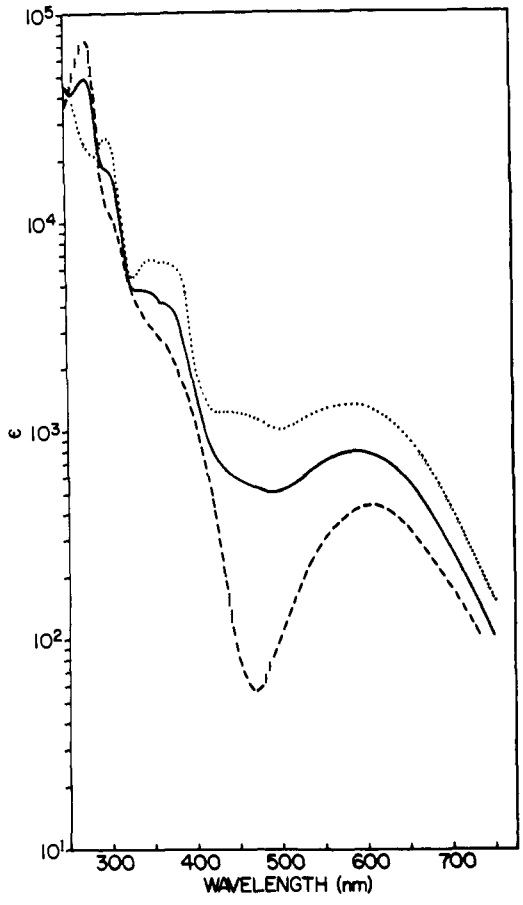


Figure 8. Electronic spectra of *anti*-[2.2](2,6)azulenophane (**1**) in chloroform and in low concentrations of trifluoroacetic acid (TFA): (- - - - - - - -) in $CHCl_3$; (—) in 0.07 M TFA; (·····) in 0.2 M TFA.

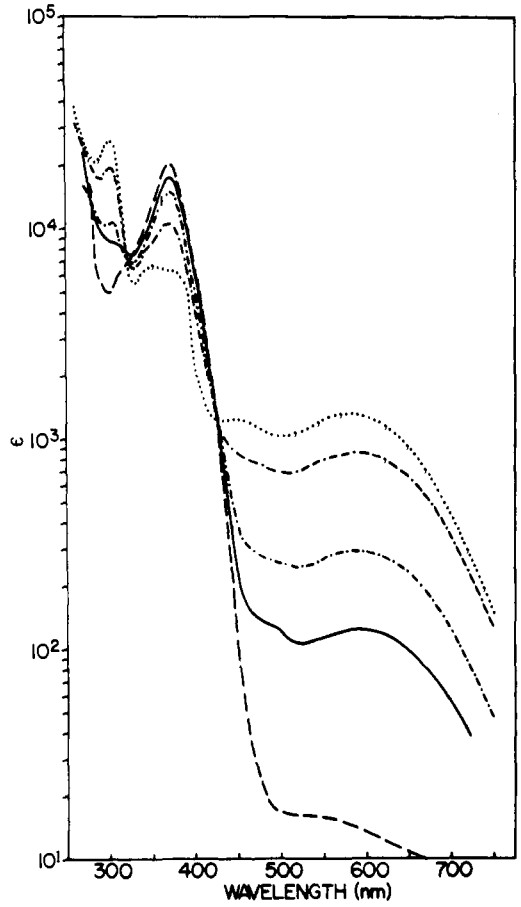


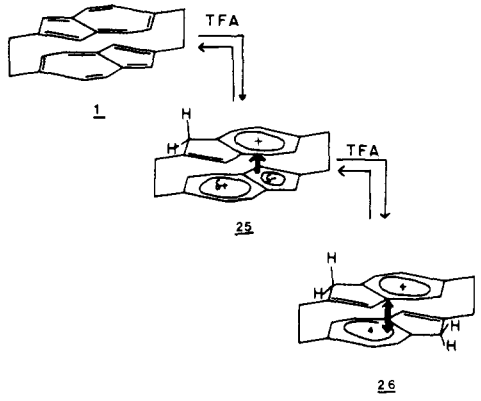
Figure 9. Electronic spectra of *anti*-[2.2](2,6)azulenophane (**1**) in high concentrations of trifluoroacetic acid (TFA): (·····) in 0.20 M TFA; (·-·-·-·-·) in 1.35 M TFA; (·-·-·-·) in 3.37 M TFA; (—) in 6.73 M (50%) TFA; (- - - - - - - -) in 13.4 M (100%) TFA.

violet band at 290 nm decrease in optical density and the band corresponding to the azulenium ion at 373 nm increases (see Figure 7). For *anti*-**1**, at low concentrations of acid (0–0,2 M TFA in $CHCl_3$) (see Figure 8) there is a general increase in optical density at the 600-nm region of the spectrum, a hypsochronic shift of this band to about 575 nm, and the appearance of a new band at 450 nm, In addition, there is an increase in optical density at 302, 350, and 375 nm, and a decrease at 279 nm, The spectrum of *anti*-**1** in 0.20 M TFA is assigned to that of the monoprotonated azulenophane **25** and indicates the existence of charge transfer in **25.** The band at 450 nm (log ϵ 3.1) is an intramolecular charge-transfer band arising from the interaction between the azulene donor and the tropylium-like acceptor.

As the acid concentration is increased (see Figure 9) diprotonation begins to occur as evidenced by the changes in the spectra. The bands at 302, 350, and 575 nm in **25** disappear with the corresponding disappearance of its charge-transfer band at 450 nm. The band at 370 nm, characteristic of the two azulenium ions, increases. The protonation of **1** is summarized in Scheme IV.

Note should be taken of the difference in the basicity of *anti*-**1** and 2,6-dimethylazulene (**16**). One of the azulene rings in *anti*-**1** is completely protonated in 0.20 M acid while **16** at this concentration of acid is only about 50% protonated. This implies that the azulene rings in *anti*-**1** are more basic than that in **16.** From another viewpoint, *anti*-**1** protonates more readily because the cation formed is stabilized compared with cation **24.** The stabilizing effect in **25** is due to the intramolecular charge-transfer interaction from the unprotonated azulene moiety to the azulenium ion, which are both rigidly fixed by the cyclophane structure in an orientation for maximum interaction, The remaining azulene ring in **25** protonates with greater difficulty as now a dication (**26**), with internal repulsive interactions, is being generated and the charge-transfer interaction is being destroyed. Dication **26** is stable for several hours in TFA and *anti*-**1** is precipitated when the TFA solution is added to water.

Scheme IV



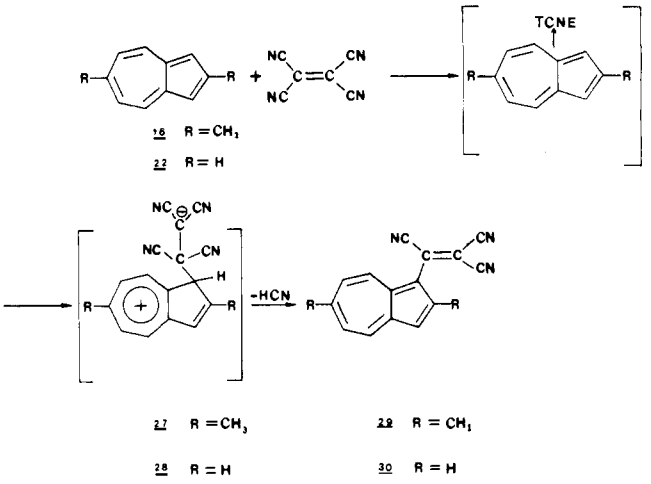
The observance of a charge-transfer interaction in the electronic spectrum of **25** represents the first example of a relatively stable interaction between azulene and tropylium moieties[20] and also the first charge-transfer interaction in a cyclophane between neutral (polarized) and charged groups,[21] It also serves to substantiate our assignment of an anti orientation in the azulenophane we have isolated, The monocation of the syn isomer **2** would be expected to be destabilized relative

to **25** as the tropylium-like ring would be layered over the partial positive dipole in the other azulene moiety,

In an attempt to confirm the charge-transfer interactions in **1** by similar spectral changes tropylium tetrafluoroborate was mixed with **1.** However, reaction was too rapid for a charge-transfer band to be observed, Presumably, the tropylium reacted with the nucleophilic 1 and 3 positions of the azulene nuclei in **1** giving rise to the cycloheptatrienyl derivative of **1.**[20]

Charge-Transfer Complexes of 1 and 16 with Tetracyanoethylene (TCNE). After observing *intra*molecular charge transfer in the monoprotonated azulenophane **25** we looked at *inter*molecular charge transfer of **16** and **1** with trinitrobenzene (TNB) and tetracyanoethylene (TCNE), both of which form charge-transfer complexes with azulenes.[19] In a $CHCl_3$ solution of 0.2 M TNB, 2,6-dimethylazulene (**16**) showed a charge-transfer band at 498 nm, while with *anti*-**1** there appeared an absorption maximum at 595 nm. With TCNE the changes were more complicated. A solution of 2,6-dimethylazulene (**16**) (4×10^{-4} M) and TCNE (1×10^{-2} M) in $CHCl_3$ was a deep blue color in agreement with the other reported TCNE-azulene complexes, with a λ_{max} at 720 nm (ϵ 1350) and a shoulder at 540 nm. After standing for 17 h at room temperature the color of the solution had changed to yellow, and the λ_{max} appeared at 420 nm (ϵ 3000). By NMR analysis the yellow material appeared to be intermediate **27** (see Scheme V) which was stable in solution. After 48 h the

Scheme V



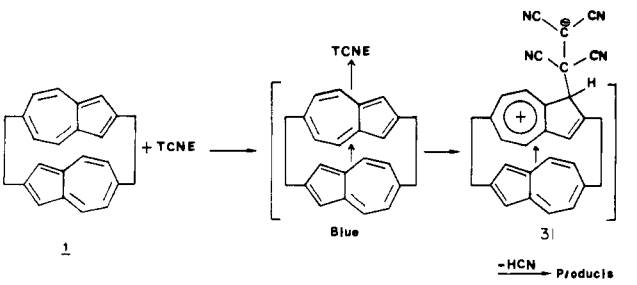
16 R = CH_3
17 R = H
27 R = CH_3
28 R = H
29 R = CH_3
30 R = H

solvent was evaporated leaving a solid which was chromatographed. One major red band was isolated, The NMR spectrum showed it to be different than the material in solution after **16** and TCNE were allowed to react for 48 h, 1-Tricyanovinylazulene (**30**) is reported to be red[22] and the major red component after removal of solvent is probably 1-tricyanovinyl-2,6-dimethylazulene. It seems that σ complex **27** is stable in solution and upon evaporation of solvent hydrogen cyanide is eliminated to give **29.**

The charge-transfer band for **1** with TCNE appeared at 830 nm (ϵ 2500) with a shoulder at 570 nm. In contrast to **16** with TCNE, however, the blue color rapidly faded and the solution became pale brown. For a solution of **1** (4×10^{-4} M) and TCNE (1×10^{-2} M) the bands at 830 and 570 nm disappeared in less than 10 min and a band at 520 nm appeared. With time, however, the 520-nm band changed also. These changes were very concentration dependent. A rapid reaction was occurring between **1** and TCNE but the nature of the products was not clear.

TCNE complexes of substituted azulenes have been studied by Hafner and Moritz.[22] By mixing equimolar solutions of TCNE and the azulene at low temperatures (−50 °C) and evaporating the solvent they were able to isolate the crystalline complexes. After the same mixtures of TCNE and the azulene were allowed to stand for 12 h at room temperature they isolated 60–80% yields of the corresponding 1-tricyanovinylazulenes (see Scheme V). Analogously with tropylium the nucleophilic 1 position of azulene reacts with the acceptor. Based on these studies a possible reaction path for **1** with TCNE is outlined in Scheme VI. The σ complex **31** is similar to the

Scheme VI



1 31

monoprotonated azulenophane **25** and it is possible that the greater reactivity of *anti*-**1** with TCNE can be attributed to **31** being stabilized by *intra*molecular charge transfer in analogy with **25.** However, a charge-transfer band (at 450 nm) similar to that in **25** was not observed in the visible spectrum of the reaction of *anti*-**1** and TCNE.

TCNE complexes of structurally related hydrocarbons as methylbenzenes show a relationship between the position of the λ_{max} of the charge-transfer band and the dissociation constant, K, of the complex.[23] If the series of complexes are arranged in order of decreasing values of λ_{max} (increasing energy), the values of K decrease in the same order. Conversely, a lower energy charge-transfer band implies that the K values are larger and that the complex forms more readily. In a series of hydrocarbon-TCNE complexes larger K values were associated with greater π-base strength of the donor hydrocarbon. Those changes in the structural features of the hydrocarbon donor which lower the energy of the ground state will lower the energy of the excited state even more.

Cram,[24] in a study of the TCNE complexes of [*m.n*]paracyclophanes, found that they formed in a molecular ratio 1:1. Evidence for transannular delocalization of charge was also exhibited since the TCNE-paracyclophane complexes absorbed at longer wavelength than any of the open chain model compounds. [2.2]Paracyclophane had a charge-transfer band at 521 nm and for *p*-xylene the band was at 460 nm.

Thus, similar to other cyclophanes, **1** is a stronger π base, has a larger K, and reacts with TCNE more rapidly than **16** due to the transannular interaction of the two azulene nuclei.

Charge Transfer in *anti*-[2.2](2,6)Azulenophane (1). Spectral evidence for *intra*molecular charge transfer in **1** was difficult to assess though the absorption extending out to 900 nm may be considered a charge-transfer band. Mulliken's theory[25] of charge transfer includes the contribution of two functions. One is the "no bond" function due to dipole-dipole interaction which should exist in *anti*-**1.** The other is the "dative" function due to transfer of an electron from the HOMO of the donor to the LUMO of the acceptor, For this transfer of electron density to occur there must be overlap between the respective HOMO and LUMO.

On a very simple level, in *anti*-**1,** if one considers each azulene as a separate entity and if one neglects through-bond interaction (in the methylene bridges), the charge-transfer transition would correspond to the transfer of electron density from the HOMO of one azulene to the LUMO of the other azulene (see Figure 10). On reflection through a plane perpendicular to the paper and through the carbons at the 2 and 6 positions HOMO is antisymmetric and LUMO is symmetric,

This implies that the two MOs are orthogonal and overlap is zero. If the two azulene rings in *anti*-**1** are centered rigidly over each other it is possible that the low overlap of the HOMO and LUMO[26] accounts for the lack of observance of strong charge transfer. On the other hand, the visible absorption in **1** beyond 750 nm, extending to 900 nm, may be a charge-transfer band which is partially masked by the more intense absorptions at 605 and 725 nm.

We are presently attempting to resolve the above question using more sophisticated techniques and are also attempting to synthesize the syn isomer, **2**, so that a comparative study of the physical properties of both these novel systems can be made.

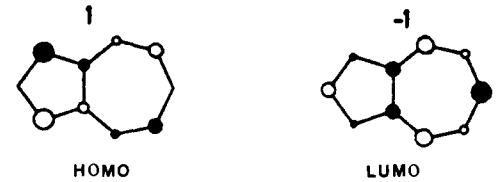


Figure 10. HOMO and LUMO of azulene.

Experimental Section

Melting points were determined on a Thomas-Hoover capillary melting point apparatus and are uncorrected. Boiling points are uncorrected. Infrared spectra were taken on a Perkin-Elmer Model 567 grating spectrophotometer. Nuclear magnetic resonance spectra were taken on a Varian Model A-60A, purchased with NIH Grant GH-13183, and on a Bruker Model WH-90, purchased with NSF Grants GU-3852 and GP 37156, spectrometers. Chemical shifts are reported in δ units, using Me_4Si as an internal standard. Ultraviolet and visible spectra were recorded on a Perkin-Elmer Model 323 or on a Cary 118 recording spectrophotometers. Mass spectra were obtained on an A.E.I. Model MS-12 mass spectrometer. Microanalyses were performed by Galbraith Laboratories, Knoxville, Tenn.

α-Methylacrylophenone (4). This compound was prepared in 66% yield by the method of Burckhalter and Fuson[6] from propiophenone.

2-Methyl-1-indanone (5). This compound was prepared quantitatively from **4** by the method of Burckhalter and Fuson,[6]

2-Methylindan (6a). This compound was prepared from **5** in 95% yield by the method of Plattner and Wyss.[7]

4-7-Dihydro-2-methylindan (7a). 2-Methylindan (69 g, 0.51 mol), liquid NH_3 (200 mL), EtOH (70 mL), and THF (199 mL) (distilled from $LiAlH_4$) were added to a 1-L three-necked flask fitted with a mechanical stirrer and a dry ice–acetone condenser. Solid sodium metal was added until the blue color persisted for 20 min. The NH_3 was allowed to evaporate overnight. The remaining residue was partitioned between ether and water. The ether layer was evaporated and the resulting liquid was again partitioned between ether and water. The ether layer was dried over $MgSO_4$ and the ether evaporated to give crude 4,7-dihydro-2-methylindan (65 g, 95%).

It is difficult to get the reduction to go to completion and on standing **7a** slowly oxidized to **6a.** A similar result was reported for the Birch reduction of indan.[8] A 5-g mixture of 95:5 **7a:6a** was separated on a $AgNO_3$-impregnated silica gel column. The column was prepared according to the procedure of deVries.[27] $AgNO_3$ (100 g) was dissolved in H_2O (200 mL). Silica gel (100 g) was added and the mixture was heated on a steam bath for 30 min. Care was taken to prevent exposure to light. The mixture was cooled and filtered. The unwashed silica gel was then heated for 12 h at 120 °C. A column was packed in hexane. The 5.0-g mixture was put on the column in hexane and the column was eluted with hexane. Fractions were collected every 100 mL. A compound with no olefinic protons (by NMR) was eluted first, followed by **6a.** Last to be eluted was **7a** which proved to be a mixture. The contaminant was not present before chromatography. Fortunately the mixture could be separated by distillation. Pure **7a** distilled at 67 °C (9 mm); the contaminant distilled at 35 °C (9 mm). NMR ($CDCl_3$) δ 5.73 (s, 2 H), 2.6 (s, 4 H), 1.5–2.5 (m, 5 H), 1.03 (d, 3 H, J = 6 Hz); IR ($CHCl_3$) 2950, 2875, 2835, 2820, 1640, 1480, 1370, 942 cm^{-1}.

Anal. Calcd for $C_{10}H_{14}$ (mol wt 132.222): C, 89.48; H, 10.51. Found: C, 89.82; H, 10.12.

4-Carbethoxy-9-methyltricyclo[5.3.0.0^{3,5}]decene-$\Delta^{1(7)}$ (8a) and 10-Carbethoxy-8-methyltricyclo[4.3.1.0^{1,6}]decene-Δ^{3} (9a). A mixture of 4,7-dihydro-2-methylindan (166 g, 1.24 mol) and 2-methylindan (19 g, 0.144 mol) was added with 25 mg of anhydrous $CuSO_4$ to a 1-L flask fitted with a mechanical stirrer, condenser, and a dropping funnel. The mixture was heated in an oil bath kept at 110 °C, Ethyl diazoacetate (0.2 equiv) was added dropwise over a period of 3 h with vigorous stirring. The mixture was cooled and distilled to recover unreacted starting material. The higher boiling fraction was set aside. The recovered starting material was reacted again with another 0.2 equiv of diazoacetic ester. This sequence was repeated four times. Of the original 185 g, 99.2 g of **7a** and **6a** were recovered. The higher boiling fractions were combined and distilled to give 105 g (75%) of an 8:2 mixture of **8a** and **9a**, bp 80–100 °C (0.05 mm). The mixture was separated using a spinning band column. Compound **8a:** bp 90 °C (0.01 mm); NMR ($CDCl_3$) δ 4.15 (q, 2 H, J = 7 Hz), 2,3 (s, 4 H), 1.25 (t, 3 H, J = 7 Hz), 1.0 (d, 3 H, J = 5 Hz), 2.3–1.0 (m, 8 H); IR ($CHCl_3$) 2950, 2900, 2838, 1720 (C=O), 1440, 1370, 1345, 1286, 1165 cm^{-1}.

Anal. Calcd for $C_{14}H_{20}O_2$ (mol wt 220.314): C, 76.33; H, 9.15. Found: C, 76.73; H, 9.25.

Compound **9a:** bp 64 °C (0.01 mm); NMR ($CDCl_3$) δ 5.5 (m, 2 H), 4.17 (q, 2 H, J = 7 Hz), 1.25 (t, 3 H, J = 7 Hz), 0.97 (d, 3 H, J = 7 Hz), 2.6–1.0 (m, 10 H); IR ($CHCl_3$) 2955, 2930, 2900, 2850, 2838, 1720 (C=O), 1440, 1365, 1290, 1170, 1135 cm^{-1}.

Anal. Calcd for $C_{14}H_{20}O_2$ (mol wt 220.314): C, 76.33; H, 9.15. Found: C, 76.35; H, 9.34.

2-Methyl-6-carbethoxyazulene (10a). Compound **8a** (1.0 g, 4.5 mmol) was dissolved in CCl_4 (50 mL) and cooled with an acetone–ice bath. Bromine (0.73 g, 4.5 mmol) dissolved in 2 mL of CCl_4 was added dropwise with stirring. When the addition was complete triethylamine (2.0 g, 20 mmol) was added. Triethylamine hydrobromide began to form immediately. The mixture was refluxed for 18 h. The hydrobromide salt (1.53 g, 94% of the theoretical amount) was filtered. It is important to recover the theoretical amount of this salt; otherwise 1-brominated azulene products are isolated. The filtrate was evaporated and the resulting oil partitioned between benzene and dilute aqueous acid. The benzene layer was washed with H_2O and dried over $MgSO_4$ and filtered. Chloranil (2.2 g, 8.9 mmol) was added to the filtrate. The mixture was stirred at room temperature for 1 day, then refluxed for 2 h. The solvent was removed and the residue extracted with hexane. The hexane extract was chromatographed on alumina. The column was eluted with benzene–petroleum ether (1:3) to give crude **10a** (0.5 g, 2.4 mmol, 50%). A sample was recrystallized from ethanol–H_2O, mp 78–79 °C. It was characterized by hydrolysis to the known acid **11a** (see preparation of **11a**).[10b] NMR ($CDCl_3$) δ 8.04 (AB q, 4 H, J = 10.5 Hz), 7.15 (s, 2 H), 4.46 (q, 2 H, J = 7 Hz), 2.72 (s, 3 H), 1.54 (t, 3 H, J = 7 Hz); IR (KBr) 2930, 2910, 1712 (C=O), 1577, 1260, 1220, 1070 cm^{-1}; UV-vis ($CHCl_3$) (log ϵ) 660 sh (2.44), 614 (2.52), 570 sh (2.41), 370 (3.78), 354 (3.78), 338 (3.60), 322 (3.23), 298 (4.89), 282 nm sh (4.78); mass spectrum *m/e* 214 (M^+), 186, 169, 144, 115.

2-Methyl-6-carboxyazulene (11a). Pure **10a** (1.0 g, 4.67 mmol) was added to a mixture of ethanol (30 mL) and 1.0 M NaOH (20 mL). After stirring at room temperature for 2.5 h, it was acidified with HCl. The resulting green precipitate was filtered, washed with H_2O, and dried to give **11a** (0.83 g, 4.46 mmol), 95.5%, mp 249–250 °C (lit. 250–251 °C):[10b] NMR ($CDCl_3$) δ 8.08 (AB q, 4 H, J = 10 Hz), 7.27 (s, 2 H), 2.71 (s, 3 H); IR (KBr) 1675 (C=O), 1580, 1500, 1280 cm^{-1}; UV-vis ($CHCl_3$) (log ϵ) 665 sh (2.36), 617 (2.53), 510 sh (2.41) 370 (3.75), 354 (3.75), 338 (3.55), 324 (3.22), 295 (4.87), 282 nm sh (4.78); mass spectrum *m/e* 186 (M^+), 141, 115, 57.

6-*N,N*-Dimethylcarboxamido-2-methylazulene (12). 2-Methyl-6-carboxyazulene (**11a,** 200 mg, 1.08 mmol) and hexamethylphosphoroustriamide (176 mg, 1.08 mmol) were refluxed in 20 mL of benzene for 1 h. The reaction mixture was extracted with aqueous NaOH. The benzene layer was washed with H_2O, dried over $MgSO_4$, filtered, and evaporated to give **12** (230 mg, 1.08 mmol, 100%). A sample was recrystallized from EtOH–H_2O: mp 114–115.5 °C; NMR ($CDCl_3$) δ 8.2 (d, 2 H, J = 10 Hz), 7.23 (s, 2 H), 7.5 (d, 2 H, J = 10 Hz), 3.44 (d, 6 H, J = 20 Hz), 3.08 (s, 3 H); IR (KBr) 3010, 2920, 2855, 1640 (C=O), 1572, 1550, 1390, 1190 cm^{-1}; UV-vis ($CHCl_3$) (log ϵ) 680 sh (1.96), 615 sh (2.40), 570 (2.46), 530 sh (2.30), 366 (3.27), 351 (3.71), 335 (3.59), 306 sh (3.81), 289 (4.87), 280 nm (4.77).

Anal. Calcd for $C_{14}H_{15}NO$ (mol wt 213.28): C, 78.84; H, 7.09; N, 6.57. Found: C, 78.94; H, 7.17; N, 6.84.

6-*N,N*-Dimethylaminomethyl-2-methylazulene (13). To a solution of $BH_3{\cdot}CH_3SCH_3$ (3.8 g, 50 mmol) in anhydrous THF (100 mL) cooled with an acetone–ice bath was added a solution of **12** (5.32 g, 25 mmol) in anhydrous THF (4 mL) under nitrogen. The reaction mixture was stirred for 10 min and then brought to reflux for 1 h. Methanol was added to destroy the excess borane.

The solvent was evaporated. Analysis by NMR showed the presence of the desired product, approximately 15% of 6-hydroxymethyl-2-methylazulene, and a very minor amount of boron complex of the amine product. (The boron amine complex can be broken by dissolving in methanol and distilling off the methanol until the distillate no longer gives a green flame test for methyl borate.) The amine was characterized as the quaternary ammonium iodide **14a** (see preparation of **14a**): NMR (CCl_4) δ 7.60 (AB q, 4 H, J = 10 Hz), 7.02 (s, 2 H), 3.48 (s, 2 H), 2.65 (s, 3 H), 2.25 (s, 6 H); IR of HCl salt (KBr) 3060–2800, 2500, 1580, 1510, 1475, 1410, 950, 860, 820, 795, 600 cm^{-1}; UV–vis of HCl salt (EtOH) (log ϵ) 690 (1.92), 627 (2,36), 580 (2.44), 540 sh (2,32), 360 sh (2.99), 347 (3.67), 332 (3.52), 304 (3.64), 284 (4.86), 276 nm (4.79); NMR of boron complex ($CDCl_3$) δ 7.97 (d, 2 H, J = 10 Hz), 7.0 (m, 4 H), 3.85 (s, 2 H), 2.47 (s, 3 H), 2.35 (s, 6 H).

***N*-(2-Methyl-6-azulyl)-*N,N,N*-trimethylammonium Iodide (14a).** The crude reaction mixture from the borane reduction of **12** (see preparation of **13**) was combined with methyl iodide (33 g) in benzene. The mixture was stirred at room temperature for 18 h. The resulting blue precipitate was filtered to give **14a** (7.0 g, 82%). The filtrate was evaporated and chromatographed on silica gel using $CHCl_3$ as eluent to give 6-hydroxymethyl-2-methylazulene (0.65 g, 15%) and the boron complex of this alcohol (100 mg). Recrystallization of a small sample of **14a** from EtOH gave a powdery blue solid which did not melt up to 340 °C: NMR (Me_2SO) δ 7.53 (AB q, 4 H, J = 10 Hz), 6.95 (s, 2 H), 4.56 (s, 2 H), 2.87 (s, 9 H), 2.24 (s, 3 H); IR (KBr) 3000, 1576, 1500, 1480, 1405, 1368, 848 cm^{-1}; UV–vis (EtOH) (log ϵ) 705 sh (1.93), 638 (2.38), 588 (2.46), 546 (2.33), 364 (3.14), 349 (3.65), 334 (3.51), 305 (3.47), 284 (4.92), 274 nm (4.82).

Anal. Calcd for $C_{15}H_{20}NI$ (mol wt 341.243): C, 52.79; H, 5.91; N, 4.10; I, 37.19. Found: C, 52.37; H, 6.21; N, 3.97; I, 37.15.

***anti*-[2.2](2,6)Azulenophane (1).** Iodide salt **14a** was converted to the chloride salt by passing a solution of **14a** (6.0 g, 18.8 mmol) in methanol through an ion exchange column packed with 60 g of Amberlite IRA-400 where the anion was chloride. The blue colored eluent was collected and the methanol was evaporated. The resulting chloride salt was converted to the hydroxide salt **14b** by passing an aqueous solution of the chloride salt through an ion exchange column containing 60 g of Amberlite IRA-400 where the anion was hydroxide.

The aqueous blue eluent was diluted with H_2O to a volume of 100 mL. It was added over a period of 5 h to a mixture of 3 L of refluxing toluene and 0.5 g of phenothiazine contained in a three-necked flask fitted with a Dean-Stark trap and a mechanical stirrer. After this time the reaction mixture was cooled and the toluene evaporated to a volume of 500 mL. The insoluble material was filtered (0.98 g of polymer) and the filtrate was evaporated to give 2.68 g of a solid.

This solid was extracted with methanol. At this point the products were separated into a methanol-soluble fraction and a methanol-insoluble fraction. The latter contained the azulenophane. The methanol was evaporated from the methanol-soluble fraction. The residue was extracted with CCl_4. Most of the phenothiazine did not dissolve. The carbon tetrachloride extract was chromatographed on a silica gel column using CCl_4, then $CHCl_3$–CCl_4 (1:9), $CHCl_3$–CCl_4 (1:3), and finally $CHCl_3$ as eluents.

The first fraction contained pure 2,6-dimethylazulene (**16,** 31.6 mg, 1.1%) identified by IR, NMR, and melting point comparison with an authentic sample (see preparation of **16**). The second fraction contained 60 mg of solid having five colored spots by thin layer chromatography. The last fraction contained 400 mg (12%) of an azulene, assigned the structure 2-hydroxymethyl-6-methylazulene (**17**). It was purified further by preparative thin layer chromatography and sublimation, mp 130–132 °C. (It is of interest that the mixture melting point with 6-hydroxymethyl-2-methylazulene was not depressed.) NMR (CD_2Cl_2) δ 7.57 (AB q, 4 H, J = 10 Hz), 7.2 (s, 2 H), 5.0 (d, 2 H), 2.6 (s, 3 H), 2.1 (t, 1 H); IR ($CHCl_3$) 3600 (OH), 2980, 2920, 2860, 1585, 1380, 1010 cm^{-1}; UV–vis ($CHCl_3$) (log ϵ) 650 sh (2.03), 588 (2.50), 554 (2.51), 361 (3.16), 347 (3.60), 333 (3.64), 289 (4.80), 282 nm (4.76); mass spectrum m/e M^+ 172.0900 (obsd), 172.0888 (calcd).

Anal. Calcd for $C_{12}H_{12}O$ (mol wt 172.228): C, 83.64; H, 7.02. Found: C, 83.28; H, 7.01.

The methanol-insoluble fraction (from the original 2.68 g of solid) was chromatographed on silica gel using $CHCl_3$ as an eluent. An impure yellow compound (about 20 mg, λ_{max} 302, 330, 353, 367, 432, and 455 nm) was eluted first, followed by impure azulenophane *anti*-**1.** Following these, two unidentified purple azulenes (about 200 mg) were eluted.

The solvent was evaporated from the fractions containing azulenophane. Fortunately, **1** is not very soluble in most solvents. The residue was extracted with CH_2Cl_2 to dissolve the impurities, leaving behind **1.** *anti*-**1** was recrystallized from $CHCl_3$. The total yield of *anti*-**1** was 125 mg (4.3%): NMR ($CDCl_3$) δ 7.65 (m, 4 H), 6.40 (m, 4 H), 6.45 (s, 4 H), 3.23 (m, 8 H); IR (KBr) 3000, 2960, 2925, 1570, 1490, 1470, 1400, 800, 640 cm^{-1}; UV–vis ($CHCl_3$) (log ϵ) 725 (2.07), 605 (2.62), 375 (3.1), 350 (3.2), 302 (4.01), 277 nm (4.84); mass spectrum m/e M^+ 308.155 (obsd), 308.156 (calcd), 154.

Anal. Calcd for $C_{24}H_{20}$ (mol wt 308.15): C, 93.46; H, 6.54. Found: C, 93.23; H, 6.66.

Summary of identified products from pyrolysis of **14b** (6 g, 18.8 mmol): polymer, 0.98 g (29%); 2,6-dimethylazulene (**16**) 32 mg (1.1%); 2-hydroxymethyl-6-methylazulene (**17**), 400 mg (12%); *anti*-[2.2](2,6)azulenophane (**1**), 125 mg (4.3%).

2,6-Dimethylazulene (16). $NaBH_4$ (40 mg, 1 mmol) and **14a** (55 mg, 0.16 mmol) were added to 2-propanol (10 mL) and refluxed for 6 h. The color changed from blue to purple. The solvent was evaporated and the residue extracted with ether. An insoluble white solid was filtered. The filtrate was chromatographed on silica gel with $CHCl_3$ as eluent. The major purple band, with largest R_f, was removed from the silica with $CHCl_3$. The solvent was evaporated and the residue sublimed to give pure **16** (10 mg, 40%): mp 99–100 °C (lit. 97 °C);[12] NMR ($CDCl_3$) δ 8.07 (d, 2 H, J = 9 Hz), 7.2 (m, 4 H), 2.67 (s, 3 H), 2.64 (s, 3 H); IR (KBr) 2900, 2850, 1580, 1500, 1408, 824 cm^{-1}; UV–vis ($CHCl_3$) (log ϵ) 652 sh (74), 585 (220), 512 sh (182), 350 (3.66), 335 (3.59), 307 (3.7), 290 (4.77), 280.5 nm (4.67).

6-Hydroxymethyl-2-methylazulene. 2-Methyl-6-carboxyazulene (**11**, 150 mg, 0.81 mmol) was dissolved in anhydrous THF (5 mL). Excess borane in THF was added. The mixture was cooled in an ice bath and stirred for 2 h. The color changed from blue to purple. Methanol was added to destroy the excess borane. The solvent was evaporated and the residue was chromatographed on silica gel with $CHCl_3$ as the eluent. Crude 6-hydroxymethyl-2-methylazulene (115 mg, 83%) was thus isolated. A sample was recrystallized from CCl_4: mp 128.5–129.5 °C; NMR ($CDCl_3$) δ 7.54 (AB q, 4 H, J = 10 Hz), 7.08 (s, 2 H), 4.62 (s, 2 H), 2.56 (s, 3 H), 2.25 (br s, 1 H); IR ($CHCl_3$) 3600 (OH), 2910, 1580, 1495, 1402, 1150, 1000 cm^{-1}; UV–vis ($CHCl_3$) (log ϵ) 660 sh (1.9), 600 sh (2.37), 562 (2.44), 520 sh (2.30), 362 (3.08), 350 (3.70), 333 (3.60), 304 sh (3.78), 288 (4.85), 279 nm (4.77); mass spectrum m/e M^+ 172.0893 (obsd), 172.0888 (calcd).

Anal. Calcd for $C_{12}H_{12}O$ (mol wt 172.228): C, 83.69; H, 7.02. Found: C, 83.72; H, 7.30.

4,7-Dihydroindan (7b). This compound was synthesized by the method of Giovanni and Wegmuller in 90% yield from indan (**6b**).[8]

4-Carbethoxytricyclo[5.3.0.0^{3,5}]decene-$\Delta^{1(7)}$ (8b). A mixture of 4,7-dihydroindan (100 g, 0.83 mol) and indan (11 g, 0.093 mol) was added with 20 mg of anhydrous $CuSO_4$ to a 1-L flask fitted with a mechanical stirrer, condenser, and dropping funnel. The mixture was heated in an oil bath kept at 110 °C. Ethyl diazoacetate (18 g, 0.16 mol) was added dropwise over a period of 1.5 h with vigorous stirring. The mixture was cooled to room temperature and distilled to give 96 g of recovered starting material and several fractions of a mixture of **8b** (12.2 g, 0.06 mol), 50%, and 10-carbethoxytricyclo[4.3.1.0^{1,6}]decene-Δ^3 (**9b,** 5.1 g, 0.024 mol), 20%, boiling range 65–100 °C (0.05 mm): NMR ($CHCl_3$) δ 4.1 (q, 2 H), 1.2 (t, 3 H), 2.5–1.1 (br m, 13 H).

6-Carboxyazulene (10b). A mixture of **8b** and **9b** (9:1) (2.06 g, 10 mmol) was reacted with bromine, triethylamine, and chloranil in the same procedure as for the preparation of **10a.** Chromatography on alumina gave 1.0 g of a blue oil containing 0.55 g, (2.75 mmol, 30%) of 6-carbethoxyazulene, and a colorless material. The blue oil was heated at reflux in ethanol–1.0 M NaOH (3:1) for 1 h. Acidification gave a 0.63-g precipitate of crude acid. A small sample was purified by preparative thin layer chromatography on silica gel, and sublimation (mp 227 °C, lit. mp 227 °C)[10b]: IR (KBr) 1690 (C=O), 1590, 1440, 1410, 1310, 770 cm^{-1}.

General Procedure for UV and Visible Spectra of Azulenium Cations and Charge-Transfer Complexes. A stock solution of the azulene was prepared in $CHCl_3$ at two concentrations, about 10^{-3} M for visible and 10^{-5} M for UV. Solutions of various concentrations of trifluoroacetic acid were prepared in $CHCl_3$. The azulene stock solution (0.5 mL) and trifluoroacetic acid solution (0.5 mL) were mixed in a 1-cm cell of 1-mL volume. Spectra of **16** and **1** with TNB and TCNE were obtained by mixing appropriate concentrations of donor and acceptor in $CHCl_3$ solution and recording the spectrum. No attempts were made to isolate the complexes because of the limited amount of starting materials available.

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Studies on the Syntheses of Heterocyclic Compounds. 700.[1a] Syntheses of Isoquinoline Alkaloids with Cuprous Chloride and Oxygen in Pyridine as an Enzymic Model

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Abstract: Phenol oxidation of (+)-reticuline (**1**) perchlorate with cuprous chloride and oxygen in pyridine gave (+)-corytuberine (**2**), (+)-isoboldine (**3**), and pallidine (**4**). Racemic 1,2,3,4-tetrahydro-7-hydroxy-1-(3-hydroxy-4-methoxyphenethyl)-6-methoxy-2-methylisoquinoline (**5**) hydrochloride yielded the ortho-ortho, ortho-para, and para-para coupling products (racemates of **6**, **7**, and **8**) under the same conditions. (±)-Orientalinone (**10** and/or **11**) and (±)-kreysiginone (**13**) were also synthesized from the corresponding 1-benzyl- and 1-phenethylisoquinolines (**9** and **12**). Oxidation with cupric chloride and potassium superoxide in pyridine also gave rise to similar results. Mechanisms of the oxidations by these reagents are discussed.

The oxidation and coupling of phenols is a subject of great importance in biochemistry and organic chemistry.[2] Furthermore, the reactions between atmospheric oxygen and phenols are of special interest in relation to autoxidation processes and enzymic processes, Oxidative reactions of phenols with molecular oxygen activated by metal salts are well known.[2-8] Many phenolic compounds in nature would also be oxidized with enzymes involving both metal and oxygen to afford complex natural products. The three main classes of enzymes known as catalyst for phenol oxidation and coupling are the laccase, the tyrosinase, and the peroxidase. The former two enzymes include copper ion and oxygen.[2]

In an isoquinoline alkaloid field, biosynthetic pathways to a variety of the alkaloid groups, for example, aporphines, morphines, proaporphines, cularines, and bisbenzylisoquinolines,[9,10] involve phenol oxidative coupling as a key reaction. However, success in demonstrating the coupling with enzymes in vitro has so far been limited.[11-13] There are nu-