11-keto-14-isoequilenin-3-methyl ether (14a), mp 158–160°,[13] *m/e* 294, whose identity was confirmed by comparison of its ir in potassium bromide with that of the optically active form **14b**, mp 187–189°, obtained by methylation of 11-keto-14-isoequilenin[14,15] with diazomethane.[18]

Elution with 5% ether in benzene yielded a solid which after recrystallization from methanol and then ether furnished 52 mg of a material, mp 164–166°, *m/e* 294. Its spectrum exhibited a hydroxyl and a peak at 5.90 μ, λ_{max} (EtOH) 222, 254, and 327 nm (ϵ 35,000, 13,000, and 3500), shifting on addition of alkali to 244 and 380 nm (ϵ 29,000 and 4000), reversible on acidification to the original wavelengths. The location of the methyl peak at 2.5 ppm shows unsaturation at the adjacent carbon atom.

Further elution with 5% ether in benzene furnished a mixture of solids, which on recrystallization from ethanol deposited 25 mg of ***rac*-11-keto-8-dehydro-14-isoestrone-3-methyl ether (15a)**: mp 174–176°; *m/e* 296; λ_{max} (KBr) 5.75 and 6.05 μ; λ_{max} (EtOH) 245, 295, and 315 nm (ϵ 17,000, 4800, and 4810). The identity of this compound was established by the Jones oxidation of an authentic sample of the corresponding 17β-ol analog **15b**,[10] and direct comparison of the product with our sample. The nonidentity with its 14α epimer, mp 161–163°, was confirmed by direct comparison with a sample of the latter.[17]

The next crop from crystallization of **15a** provided yet another material. Recrystallization furnished 53 mg, mp 192–193°, *m/e* 312, exhibiting a hydroxyl absorption and a carbonyl at 5.75 μ, λ_{max} (EtOH) 275 and 281 nm (ϵ 1500 and 1400), and a peak at 3.73 ppm.

Acknowledgment. The authors wish to thank Ester Abramovici for analytical data, Betty Poplinger and Yosi Ben-Ephraim for technical assistance, and Professor Y. Mazur for helpful discussions.

Registry No.—**1a**, 51270-51-0; **1b**, 51270-52-1; **1c**, 51270-53-2; **2**, 26828-48-8; **3**, 51270-54-3; **4a**, 21403-95-2; **4b**, 20915-80-4; **5a**, 51270-55-4; **5b**, 51270-56-5; **6**, 51270-57-6; **7**, 51270-58-7; **8**, 51270-59-8; **9**, 51270-60-1; **10**, 899-79-6; **11b**, 24421-61-2; **12**, 41021-02-7; **13**, 51270-61-2; **14a**, 26584-94-1; **15a**, 26435-94-9; **16**, 51270-62-3; *m*-chloroperbenzoic acid, 937-14-4.

References and Notes

(1) M. S. Newman and J. H. Manhart, *J. Org. Chem.*, **26**, 2113 (1961).
(2) E. W. Colvin, J. Martin, and B. Shroot, *Chem. Ind. (London)*, 2130 (1966).
(3) U. K. Pandit, K. de Jonge, and H. O. Huisman, *Recl. Trav. Chim. Pays-Bas*, **88**, 149 (1969).
(4) For a summary of the different variants see (a) H. O. Huisman, *Angew. Chem., Int. Ed. Engl.*, **10**, 450 (1971); (b) H. O. Huisman, "MTP International Review of Science," Vol. 8, W. F. Johns, Ed., Butterworths, London, 1973, Chapter 9.
(5) H. Wehrli, C. Lehman, P. Keller, J. J. Bonet, K. Schaffner, and O. Jeger, *Helv. Chim. Acta*, **49**, 2218 (1966).
(6) A. V. Zakharychev, J. Hora, E. Abu Mustafa, S. N. Ananchenko, and I. V. Torgov, *Izv. Akad. Nauk SSSR, Ser. Khim.*, 1351 (1970); *Chem. Abstr.*, **74**, 13322j (1971).
(7) A. R. Daniewski, M. Guzewska, M. Kocór, and J. S. Baran, *Bull. Acad. Pol. Sci., Ser. Sci. Chim.*, **19**, 313 (1971).
(8) A. R. Daniewski, M. Guzewska, and M. Kocór, *Bull. Acad. Pol. Sci., Ser. Sci. Chim.*, **21**, 91 (1973).
(9) (a) A. J. Birch and G. S. R. Subba Rao, *Aust. J. Chem.*, **23**, 547 (1970); (b) *Tetrahedron Lett.*, 2763 (1967).
(10) R. P. Stein, G. C. Buzby, G. H. Douglas, and H. Smith, *Tetrahedron Lett.*, 3603 (1967).
(11) V. L. Sadovskaya, N. S. Vul'fson, and V. I. Zaretskii, *Izv. Akad. Nauk SSSR, Ser. Khim.*, 2767 (1967); *Chem. Abstr.*, **69**, 2702m (1968).
(12) C. K. Kuo, D. Taub, and N. L. Wendler, *J. Org. Chem.*, **33**, 3126 (1968), and references cited therein.
(13) We assume that the mp 160–171° reported for **14a**[9a] should read 160–161°, since in the preliminary communication[9b] mp 158–160° was reported.
(14) "Inactive 11-oxoequilenin" described[15] is in fact 11-keto-14-isoequilenin, for hydrogenolysis of its 3-methyl ether for 4 hr at room temperature in acetic acid solution, in the presence of 5% palladium on charcoal and perchloric acid, afforded 14-isoequilenin-3-methyl ether, mp 116–118° (lit.[16] mp 119° and, for equilenin-3-methyl ether, mp 193–194°). Furthermore, the above methyl ether, mp 187–189°, was not changed by heating with hydrochloric acid–acetic acid (1:4) for 1 hr at 100°, treatment which might be expected to cause isomerization of 11-ketoequilenin-3-methyl ether to **14b**.
(15) N. L. McNiven, *J. Amer. Chem. Soc.*, **76**, 1725 (1954).
(16) W. E. Bachmann, W. Cole, and A. L. Wilds, *J. Amer. Chem. Soc.*, **62**, 824 (1940).
(17) Kindly provided by Dr. Richard W. Rees of the Wyeth Laboratories, Inc.
(18) Note Added in Proof. We have now prepared **14a** also by polyphosphoric acid cyclization of the pure "unnatural" stereoisomer of *rac*-5-(6-methoxy-2-naphthyl)-1-methyl-2-oxocyclopentane-1-acetic acid, mp 151–153° [E. G. Brain, F. Cassidy, M. F. Constantine, J. C. Hanson and D. J. D. Tidy, *J. Chem. Soc. C*, 3846 (1971)], kindly provided by Dr. Brain of the Beecham Laboratories. The product, mp 158–159°, was identical with **14a** described above.

Nonbenzenoid Aromatic Systems. X.[1a] Formation, Nuclear Magnetic Resonance Spectral Identification, and Reactions of Both Meisenheimer Type and Methyleneazulenate Anions

Richard N. McDonald,* Herbert E. Petty,[1b] N. Lee Wolfe, and Joseph V. Paukstelis

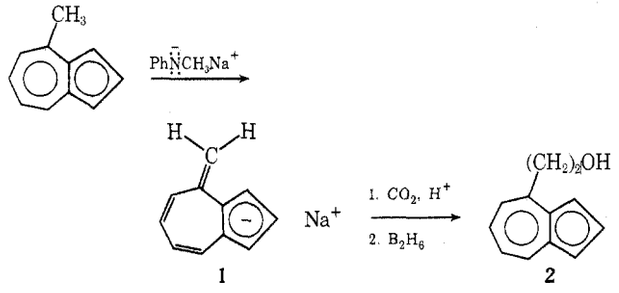
Department of Chemistry, Kansas State University, Manhattan, Kansas 66502

Received March 26, 1974

The reaction products from azulene and certain methylazulenes with several nucleophilic strong bases have been observed and identified by nmr spectroscopy. With azulene, lithium dicyclohexylamide (**3**) and tritylsodium (**18**) yield exclusively products of nucleophilic addition to the ring 6 position, 6-X-6*H*-azulenate anions, while, with lithium dimethylamide (**15**), methyllithium (**23**), and sodium methylsulfinylmethide (**27**), products derived from nucleophilic addition to both the azulene ring 4 (predominant) and 6 positions are observed. The Meisenheimer type of addition complexes formed with the amide nucleophiles (**3** and **15**) and azulene were shown to thermally equilibrate while those complexes resulting from ring addition by the carbon nucleophiles (**18**, **23**, and **27**) were thermally stable. Competitive nucleophilic addition and methyl group proton abstraction reactions were examined with some of these nucleophilic bases and 4,6,8-trimethylazulene (**31**). Exclusive proton abstraction was observed in the reaction of sodium *N*-methylanilide, **18**, or **27** with **31** to yield mixtures of the methyleneazulenate anions **32** and **33**. However, amide **15** reacted with **31** by nucleophilic addition to the 4 and 6 positions, the initially formed mixture being thermally equilibrated. Carbonation of lithium 6-dicyclohexylamino-6*H*-azulenate (**20**) yields a mixture of azulene mono- (1 and 2), di- (1,2 and 1,3), and tricarboxylic (1,2,3) acids. Carbonation of a mixture of lithium 6-dimethylamino-6*H*-azulenate and its 4 isomer yields only azulene. Other related reactions are presented, and discussions of the involved processes are given.

Our investigations of the effects of the five nonequivalent azulene ring positions on the solvolysis of β-azulylethyl arenesulfonates have thus far dealt with the ethyl side chain attached to the azulene 1,[2] 4,[3] and 6 positions.[3] 2-(1-Azulyl)ethanol was synthesized by electrophilic substitution of azulene.[4] The 2-(4- (**2**) and 2-(6-azulyl)ethanol

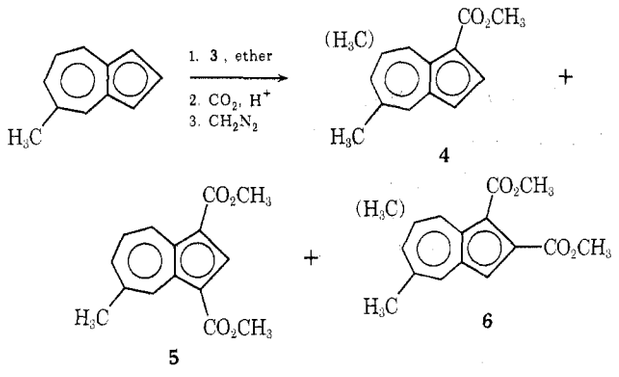
were prepared by carbonation of the 4- (1) and 6-methyleneazulenate anions,[5] respectively, followed by reduction of the corresponding acetic acids. The present work begins with our attempts to utilize the latter procedure to produce 2-(5-azulyl)ethanol.



1 2

Products from Reactions of Azulenate Anions. The number of known 5-substituted azulenes which might be converted to 2-(5-azulyl)ethanol is very limited. Since the methyl group of 5-methylazulene is not activated toward proton abstraction as are those of 4- and 6-methylazulene,[6] it was felt that proton abstraction might result if a strong, sterically hindered base were employed.[7] The base chosen for this purpose was lithium *N,N*-dicyclohexylamide (**3**).[8]

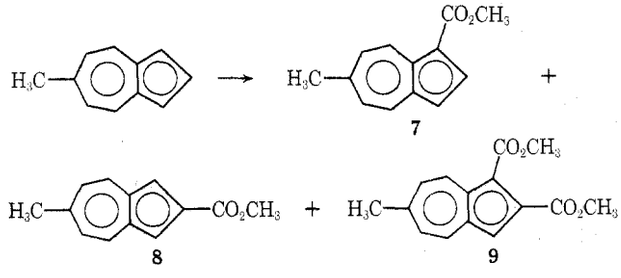
Reaction of **3** and an excess of 5-methylazulene in ether resulted in no visible color change. Carbonation of the reaction mixture produced base-soluble products but nmr spectral analysis of the acidic product showed that the desired 5-azulylacetic acid had *not* been formed. Reaction with diazomethane and chromatography gave a mixture of methyl 5- (7-) methyl-1-azulenecarboxylate (**4**, 17.0%, 42.3% net), dimethyl 5-methyl-1,3-azulenedicarboxylate (**5**, 2.2%, 5.5% net), and dimethyl 5- (7-) methyl-1,2-azulenedicarboxylate (**6**, 0.9%, 2.3% net).



4

5 6

When **3** was allowed to react with 6-methylazulene in ether and the resulting yellow solution was carbonated followed by conversion of the acids to their methyl esters, a mixture of methyl 6-methyl-1-azulenecarboxylate (**7**, 8.3%, 32% net), methyl 6-methyl-2-azulenecarboxylate (**8**, 3.3%, 12.8% net), and dimethyl 6-methyl-1,2-azulenedicarboxylate (**9**, 5.0%, 19.2% net) was obtained. This result was unexpected since reacion of 6-methylazulene with sodium *N*-methylanilide in ether followed by carbonation produced 6-azulylacetic acid.[3,5]

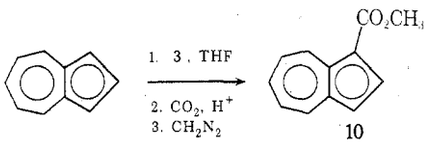


7

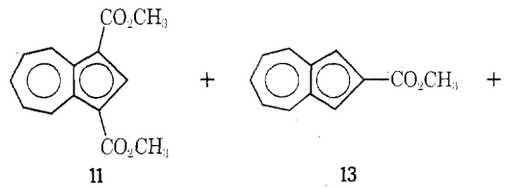
8 9

A solvent effect was noted in the reaction of **3** with 6-methylazulene. In tetrahydrofuran, the results of carbonation gave 36% of recovered 6-methylazulene and 39% of 6-azulylacetic acid. Similar conditions with 4-methylazulene yielded 22% recovered 4-methylazulene and a 70% yield of 4-azulylacetic acid.

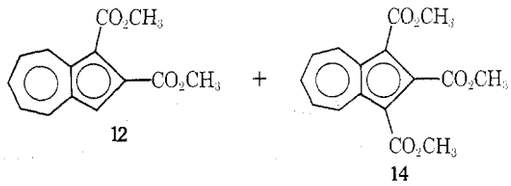
To demonstrate that the methyl groups of 5- and 6-methylazulene were not involved in formation of the nuclear carbonation products, azulene was similarly allowed to react with **3** in ether followed by carbonation and conversion of the acidic products to their methyl esters. The mixture of esters was composed of methyl 1-azulenecarboxylate (**10**, 13.7%, 71% net), dimethyl 1,3-azulenedicarboxylate (**11**, 2.3%, 13.5% net), and dimethyl 1,2-azulenedicarboxylate (**12**, 1.4%, 7.5% net). When this reaction was run on a larger scale with tetrahydrofuran as solvent the ester product mixture contained 11% (23% net) **10**, 5% (10% net) methyl 2-azulenecarboxylate (**13**), 4% (8% net) **11**, 5% (11% net) **12**, and 1% (2% net) trimethyl 1,2,3-azulenetricarboxylate (**14**).



10



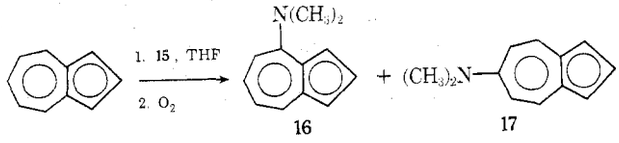
11 13



12 14

When lithium dimethylamide (**15**) was allowed to react with azulene in ether, the color of the solution immediately changed from blue to yellow. Addition of carbon dioxide to this yellow solution regenerated the azulene blue color. When water was added effervescence resulted and work-up of the reaction yielded only recovered azulene. Substitution of methanol (a proton source) for carbon dioxide or changing the solvent to tetrahydrofuran or benzene produced the same result.

To establish the gross structure of the adduct(s) from reaction of **15** and azulene, the reaction mixture was treated with oxidizing agents. Bubbling oxygen through the reaction mixture at −70° produced no color change, but as the temperature was slowly increased the solution turned blue. Work-up of the resulting mixture gave 4- (**16**, 8%) and 6-*N,N*-dimethylaminoazulene (**17**,[12] 12%). When



16 17

the reaction mixture from **15** and azulene was allowed to equilibrate at 25° and oxygen was added, the two amines **16** and **17** were isolated in 4 and 18% yields, respectively.

Table I
Visible λ_{max} for Certain 4- and 6-Substituted Azulenes

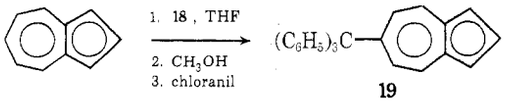
Compd	Solvent	λ_{max}, nm	Ref
Azulene	Cyclohexane	580	9
4-CH_3Az	Cyclohexane	568	9
6-CH_3Az	Cyclohexane	565	9
4-H_2NAz	CH_2Cl_2	510	10
4-$(CH_3)_2$NAz (**16**)	Cyclohexane	546	This work
6-H_2NAz	CH_3OH	465	11
	C_2H_5OH	470	
6-$(CH_3)_2$NAz (**17**)	CH_3OH	472	12, this
	Cyclohexane	486	work
6-$(C_2H_5)_2$NAz	CH_3OH	476	12

With chloranil as the oxidizing reagent, only amine **16** was isolated.

The λ_{max} of the visible spectra of **16** and **17** deserve comment. For many 4 and 6 substituents on the azulene ring, $\Delta\lambda_{max}$ is essentially constant, *e.g.*, the 4- and 6-methylazulenes in Table I. Generally, electron-donating substituents cause a hypsochromic shift and electron-withdrawing substituents result in a bathochromic shift of this absorption band. However, as can be seen from the data in Table I, the λ_{max} values for the azulylamines are quite different. The difference, $\Delta\lambda_{max}$, between **16** and **17** of +60 nm is attributed to a steric interaction between the 4-dimethylamino group and the peri-C_3 hydrogen[9] in **16** which is not present in **17**. This results in a steric inhibition of conjugation between the azulene ring and the nitrogen nonbonded pair of electrons. The stable conformation of **16** would probably have the peri-C_3 hydrogen roughly bisecting the nonbonded electron pair–nitrogen–methyl angle. It is interesting to note that 4-*N*-acetylaminoazulene has λ_{max} (CH_2Cl_2) 560 nm.[10a] In this case, the reduced availability of the nitrogen nonbonded electron pair for conjugation with the ring is probably electronic rather than steric.

An orange solution resulted when azulene was allowed to react with tritylsodium (**18**) in tetrahydrofuran at −70°. Addition of methanol produced a colorless solution which when dehydrogenated with chloranil gave a blue solution. From this solution a blue, crystalline solid was isolated which failed to yield sharp-melting crystals even after repeated column chromatography and recrystallizations.[13]

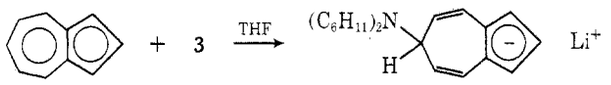
This blue solid is believed to be 6-tritylazulene (**19**) on the basis of the reaction which produced it and the spectral data. The nmr spectrum showed only the presence of aromatic protons; integration of the downfield doublet attributed to the azulyl C_4 and C_8 protons and the remaining 20 protons gave a 2:19 ratio. The mass spectrum gave M^+ at *m/e* 370 (50%) with strong ion abundances for *m/e* 243 (24%) and 127 (11%); however, ions at *m/e* 244 (10%) and 128 (6%) may be due to triphenylmethane and azulene contamination.[13] The visible spectrum had λ_{max} (cyclohexane) 579 nm, which was about that predicted for **19**.[14]



19

Nmr Spectral Investigation of Azulenate Anion Structures. The ability to produce the diverse mono-, di-, and trinuclear carbonation products **10**–**14** by carbonation of the product derived from reaction of azulene and the lithium dicyclohexylamide (**3**) prompted us to investigate the structure of this product and those derived from reactions involving other strongly basic nucleophiles and azulene. To obtain structural information on such reactive species, nmr spectroscopy appeared to be particularly suited to the task.

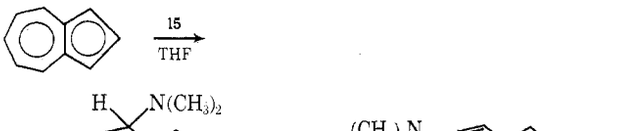
To a tetrahydrofuran solution of azulene in an nmr tube at 0° was added dropwise with shaking a solution of **3** in tetrahydrofuran until a yellow color resulted (small molar excess of **3** required). The spectrum is reproduced in Figure 1a and is interpreted as the exclusive production of lithium 6-*N,N*-dicyclohexylamino-6*H*-azulenate[16] (**20**). See Table II for a numerical listing of the proton absorptions and their assignments.[17,18] No change in the spectrum of this Meisenheimer type complex was observed after 36 hr at 33°.



20

The simplicity of the spectrum readily allows structural assignments to the three distinct spectral patterns, the C_1, C_2, and C_3 protons contributing to the broadened singlet at δ 5.61, the C_4 and C_8 protons absorbing at δ 6.24 as a doublet ($J_{4,5}$ = 10.5 Hz), and the C_5 and C_7 protons absorbing at δ 4.86 as a doublet of doublets ($J_{4,5}$ = 10.5 and $J_{5,6}$ = 4.5 Hz). The cyclohexyl and C_6 ring protons would be further upfield under the solvent absorptions.

When equimolar amounts of tetrahydrofuran solutions of azulene and lithium dimethylamide (**15**) were mixed at −70° the solution color immediately turned to a light yellow. The nmr spectrum recorded at −20° was interpreted as showing the presence of lithium 4-*N,N*-dimethylamino-4*H*-azulenate (**21**) and lithium 6-*N,N*-dimethylamino-6*H*-azulenate (**22**). Integration of the C_5 and C_7 protons of **22** and the C_5 proton of **21** gave the **21**:**22** ratio as about 4:1. (See Figure 1 and Table II for the proton assignments.)



21 **22**

Warming the solution of **21** and **22** to −10° and then to 0° produced no change in the spectrum. With the sample at 10° the doublet at δ 6.71 at lower temperatures was observed as a pair of doublets and integration gave the **21**:**22** ratio as 7:3. Warming the sample to higher temperatures (Figure 1c) produced further changes in the **21**:**22** ratio (33°, 3:7; 50°, 1:4). The observed changes in the **21**:**22** ratio as a function of temperature will be dealt with further in the Discussion.

Hafner[19] reported that addition of methyllithium (**23**) to azulene followed by protonation and dehydrogenation of the dihydro product with chloranil produced only 4-methylazulene.[20] When azulene (in tetrahydrofuran) was allowed to react with an equimolar amount of **23** (in ether) at −70° a yellow-green solution resulted. The nmr spectrum was recorded at −33° (Figure 2a) and was analyzed as a mixture of lithium 4-methyl-4*H*-azulenate (**24**) and lithium 6-methyl-6*H*-azulenate (**25**) in approximately a 9:1 ratio, respectively. The spectrum showed no change on standing for 24 hr at 25°. Addition of **23** to azulene at 25 or 50° produced the same **24**:**25** ratio as that found at −70°. The five-membered ring proton chemical shifts of **24** and **25** were readily verified by carrying out the reaction with azulene-*1,3-d*$_2$.

Table II
Nmr Spectral Data for the Meisenheimer-Type Complexes of Azulenate Anions[a,i]

Reactants	Nmr solvent	Product	Proton positions 1,3	2	4	8	5	7	6	Other
Azulene + $(C_6H_{11})_2NLi$ (**3**)[b,e]	THF	**20**	5.61[f] s		6.24 d $J_{4,5}$ = 10.5		4.86 d of d $J_{4,5}$ = 10.5 $J_{5,6}$ = 4.5		*g*	
Azulene + $(CH_3)_2NLi$ (**15**)[b,e]	THF	**21**	5.83 d $J_{1,2}$ = 2.0	5.57 t $J_{1,2}$ = 2.0	*g*	6.71 d $J_{7,8}$ = 10.5	5.18 d of d $J_{5,6}$ = 10.5 $J_{4,5}$ = 7.5	5.32 d of d $J_{7,8}$ = 10.5 $J_{6,7}$ = 7.5	6.07 d of d $J_{5,6}$ = 10.5 $J_{6,7}$ = 7.5	
		22	5.85[f] m		6.65 d $J_{4,5}$ = 10.5		4.97 d of d $J_{4,5}$ = 10.5 $J_{5,6}$ = 4.5		*g*	
Azulene + CH_3Li (**23**)[b,e]	THF	**24**	5.20 d $J_{1,2}$ = 2.5	5.54 t $J_{1,2}$ = 2.5	*g*	6.60 d $J_{7,8}$ = 10.5	5.10 d of d $J_{5,6}$ = 10.5 $J_{4,5}$ = 5.2	5.36 d of d $J_{6,7}$ = 6.2 $J_{7,8}$ = 10.5	5.65 d of d $J_{5,6}$ = 10.5 $J_{6,7}$ = 6.2	
		25	5.51–5.61[f] m		6.26 d of d $J_{4,5}$ = 9.5 $J_{4,6}$ = 1.5		4.62 d of d $J_{4,5}$ = 9.5 $J_{5,6}$ = 4.0		*g*	
Azulene-*1,3*-d_2 + CH_3Li (**23**)[b,e]	THF	**24**		5.48 s	*g*	6.56 d $J_{7,8}$ = 10.5	5.10 d of d $J_{5,6}$ = 10.5 $J_{4,5}$ = 5.2	5.37 d of d $J_{7,8}$ = 10.5 $J_{6,7}$ = 6.2	5.62 d of d $J_{5,6}$ = 10.5 $J_{6,7}$ = 6.2	
		25		h	6.25 d of d $J_{7,8}$ = 9.5 $J_{6,8}$ = 1.5		4.61 d of d $J_{5,6}$ = 4.0 $J_{4,5}$ = 9.5		*g*	
Azulene + CH_3Li (**23**)[c,d]	DMSO-d_6	**24**	5.19 d $J_{1,2}$ = 2.5	5.56 t $J_{1,2}$ = 2.5	3.14 "t" J_{4,CH_3} = 6.5	6.62 d $J_{7,8}$ = 10.5	4.60–5.05 m			4-CH_3 1.97 d J_{4,CH_3} = 6.5
Azulene + $(C_6H_5)_3CNa$ (**18**)[b,e]	THF	**26**	5.88[f] s		6.49 d $J_{4,5}$ = 9.5		4.79 d of d $J_{4,5}$ = 9.5 $J_{5,6}$ = 4.0		*g*	
Azulene + CH_3SOCH_2Na (**27**)[b,e]	DMSO-d_6	**28**	5.54 d $J_{1,2}$ = 2.5	5.13 t $J_{1,2}$ = 2.5	3.57 d $J_{4,5}$ = 6.5	6.55 d $J_{7,8}$ = 10.5	4.98 d of d $J_{4,5}$ = 6.5 $J_{5,6}$ = 10.0	*h*	5.67 d of d $J_{6,7}$ = 7.0 $J_{5,6}$ = 10.0	
		29	5.50–5.60[f] m		6.34 d $J_{4,5}$ = 9.5		5.90 d $J_{4,5}$ = 9.5			
4,6,8-Trimethylazulene + $(CH_3)_2NLi$ (**15**)[b,e]	THF	**34**	6.00 d $J_{1,2}$ = 4.2	5.86 one line of the t			5.91 s	5.07 s		
		35	5.81 d $J_{1,2}$ = 4.2	5.57 t $J_{1,2}$ = 4.2			5.41 s			

[a] Chemical shifts are in δ and coupling constants are given in hertz. [b] Internal TMS standard. [c] Internal DMSO-d_5 standard. [d] Recorded on a T-60 spectrometer. [e] Recorded on XL-100 spectrometer. [f] Signals could not be resolved. [g] Signals could not be observed because of overlap with solvent absorptions. [h] Signals could not be observed because of overlap with signals of the major isomer. [i] s = singlet, d = doublet, t = triplet, and m = multiplet.

Table III
Nmr Spectral Data for the Methylenazulenate Anions[a,h]

Reactants	Nmr solvents	Product	Proton positions 1,3	2	5	7	CH_3	CH_2
4-Methylazulene + $C_6H_5N(CH_3)Na$ (**30**)[c,d]	DMSO-d_6	**1**	—— 5.40–6.20[f] —— m		—4.90–5.30[f]— m			3.91 and 4.42 d's J_{gem} = 3.7
4,6,8-Trimethylazulene + $C_6H_5N(CH_3)Na$ (**30**)[c,d]	DMSO-d_6	**32**	6.02 d $J_{1,2}$ = 3.2	*f*	5.93 s	5.03 s	2.24 and 2.02	3.81 and 4.32 d's J_{gem} = 3.7
		33	5.86 d $J_{1,2}$ = 3.2	5.56 t $J_{1,2}$ = 3.2	—5.22— s		2.08 s	3.83 s
4,6,8-Trimethylazulene + CD_3SOCD_2Na (**27**)[b,e]	DMSO-d_6	**32**	6.22 d $J_{1,2}$ = 3.2	*f*	6.12 s	5.28 s	*g*	4.03 and 4.55 d's J_{gem} = 6.0
		33	6.06 d $J_{1,2}$ = 3.2	5.80 t $J_{1,2}$ = 3.2	—5.61— s		2.33 s	4.06 s
4,6,8-Trimethylazulene + $(C_6H_5)_3CNa$ (**18**)[b,e]	THF	**32**	6.09 broad s	*f*	5.97 s	5.13 s	*f*	3.95 and 4.53 s's
		33	5.94 d $J_{1,2}$ = 3.0	5.68 t $J_{1,2}$ = 3.0	—5.45— s		*g*	3.98 s

[a] Chemical shifts are in δ and coupling constants are given in hertz. [b] Internal TMS standard. [c] Internal DMSO-d_5 standard. [d] Recorded on a T-60 spectrometer. [e] Recorded on a XL-100 spectrometer. [f] Signals could not be resolved. [g] Signals could not be observed because of overlap with solvent absorptions. [h] s = singlet, d = doublet, t = triplet, and m = multiplet.

24 **25**

When the solvent was removed from the mixture of **24** and **25** and the residue was dissolved in dimethyl sulfoxide-d_6, only the nmr spectrum of **24** could be observed. While we do not believe that **24** and **25** can equilibrate, we can only guess that a trace of water was introduced into the system during the exchange of solvents, causing destruction of **25**. However, the proton absorptions from its conjugate acid were not observed.

Addition to azulene by the bulky carbon nucleophile tritylsodium (**18**) also occurred. A tetrahydrofuran solution of azulene was "titrated" with **18** until the color of the solution was orange. The nmr spectrum (Figure 2b) was quite similar to that of **20** and indicated the presence of a single addition product, sodium 6-trityl-6*H*-azulenate (**26**) (see Table II for the proton assignments).

26

The third carbon nucleophile investigated was sodium methylsulfinylmethide (**27**). Mixing equimolar amounts of azulene and **27**-d_5 in DMSO-d_6 at 25° produced a yellow solution. Analysis of the nmr spectrum of this solution showed that it contained a mixture of sodium 4-methylsulfinylmethyl-d_5-4*H*-azulenate (**28**) and sodium 6-methylsulfinylmethyl-d_5-6*H*-azulenate (**29**) in a 9:1 ratio (Figure 2c). The **28**:**29** ratio did not change with time at 25°.

28 **29**

In each of the above cases, both nitrogen bases (**3** and **15**) and the three carbon bases (**18**, **23**, and **27**) reacted with azulene by addition to the ring 4 and/or 6 positions, yielding azulenate anions. It was of interest to us to determine how this addition reaction (a type of Meisenheimer complex formation) would compete with proton abstraction from the methyl groups of 4- and 6-methylazulene which yield the corresponding methyleneazulenates (*e.g.*, **1**).

To standardize our analysis of the nmr spectra of such methyleneazulenates, **1** was prepared by reaction of 4-methylazulene and sodium *N*-methylanilide (**30**) in tetrahydrofuran. Replacing this solvent with DMSO-d_6 and analysis of the nmr spectrum determined in the latter solvent produced the results given in Table III for **1**.

4,6,8-Trimethylazulene (**31**) reacted with **30** in tetrahydrofuran at 25° to produce a yellow solution. The solvent was replaced with DMSO-d_6 and the nmr spectrum was recorded at 33°; see Table III. The spectrum can be accounted for as a mixture of sodium 6,8-dimethyl-4-methyleneazulenate (**32**) and sodium 4,8-dimethyl-6-methyleneazulenate (**33**); the spectrum was not integrated. Carbonation of the mixture gave a 79% yield of a mixture of 6,8-dimethyl-4-azulylacetic acid (45%) and 4,8-dimethyl-

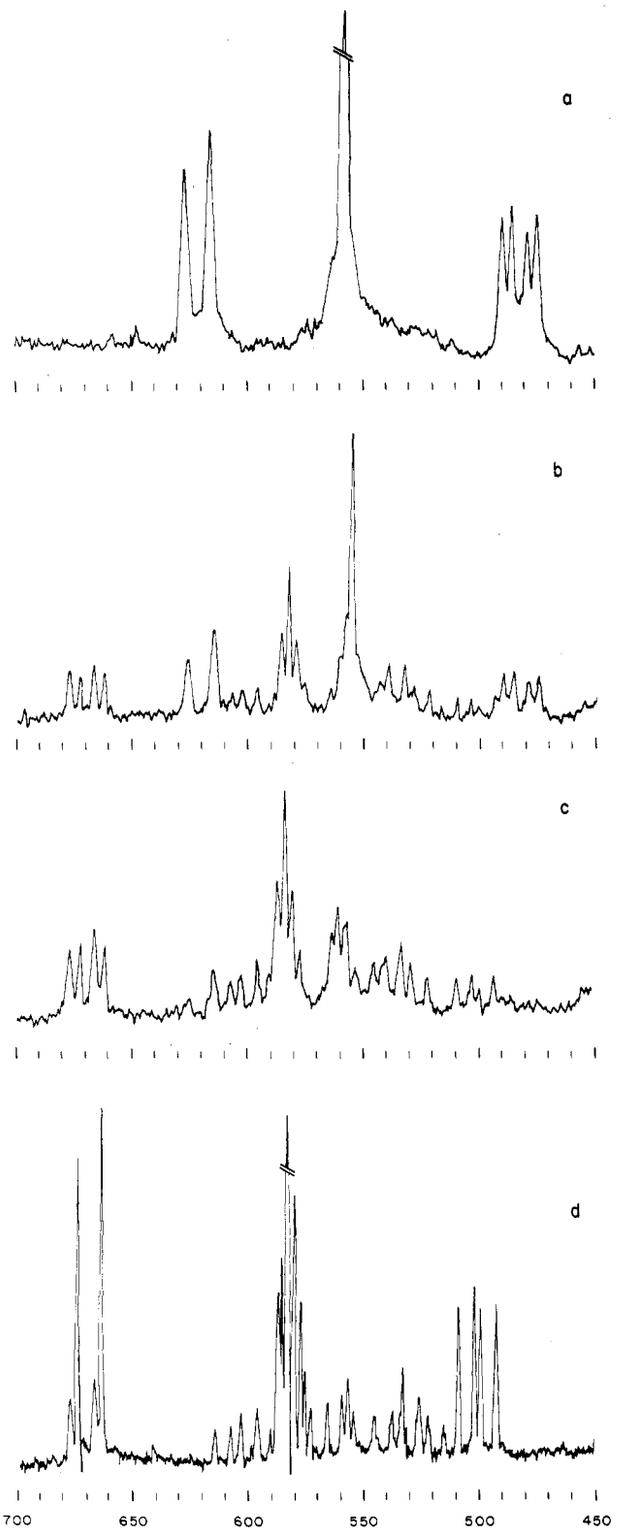


Figure 1. XL-100 spectra at −20° of (a) lithium 6-*N,N*-dicyclohexylamino-6*H*-azulenate (**20**) in THF, (b) THF solution of lithium dimethylamide added to (a) after 18 min at −20° giving a mixture of **20**, lithium 4-dimethylamino-4*H*-azulenate (**21**), and lithium 6-dimethylamino-6*H*-azulenate (**22**), (c) same as (b) but after 75 min at −20°, and (d) after 90 min at −20° and 20 min at 33°; scale in hertz.

6-azulylacetic acid (55%). Carrying out the formation of **32** and **33** at 25° and carbonation at −70 and −30° had only a negligible effect on the acid product composition.

When equimolar amounts of **31** and **27**-d_5 were allowed to react in DMSO-d_6 at 25° an orange solution resulted. While the seven-membered ring proton assignments of **32**

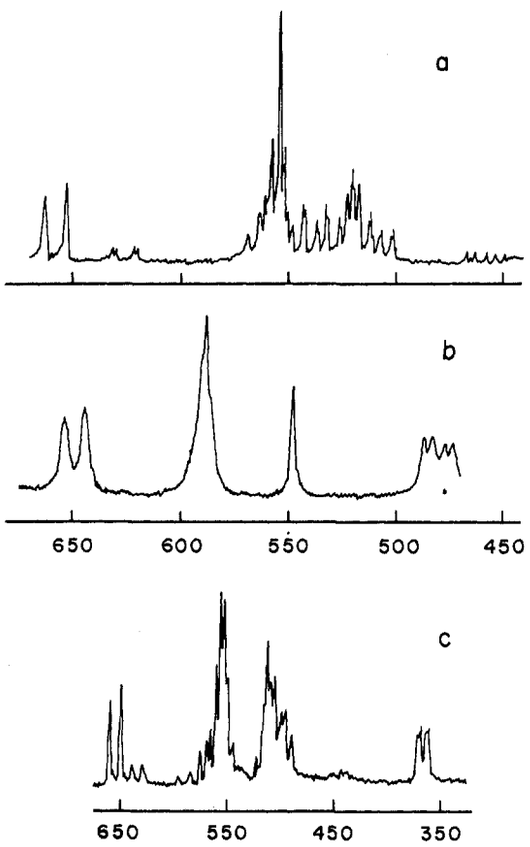
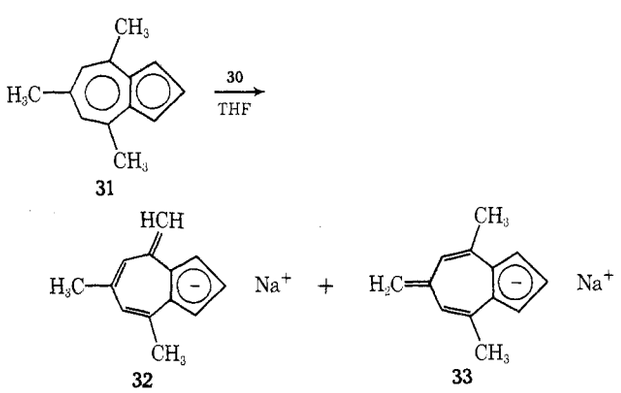


Figure 2. XL-100 spectra of (a) a mixture of lithium 4-methyl-4*H*- (**24**) and lithium 6-methyl-6*H*-azulenate (**25**) in THF, (b) sodium 6-trityl-6*H*-azulenate (**26**) in THF (peak at 546 Hz is Ph_3CH), and (c) a mixture of sodium 4-methylsulfinylmethyl-d_5-4*H*- (**28**) and sodium 6-methylsulfinylmethyl-d_5-6*H*-azulenate (**29**) in DMSO-d_6; scale in hertz.



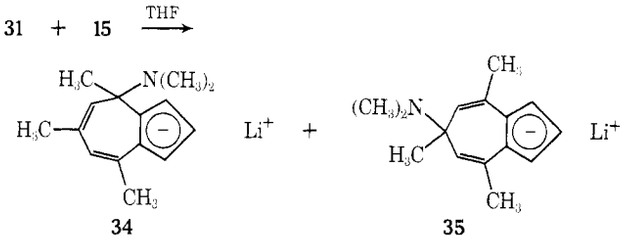
in this medium are tentative (Table III), the nmr spectrum indicated that the product of this reaction was a mixture of **32** and **33** formed by proton abstraction. Integration of C_6 methylene *vs.* the C_5 and C_7 ring protons of **33** indicated about 28% deuterium exchange of the C_6-methylene protons with solvent after standing for 2 hr at 25°. Repeating this reaction with **27** in DMSO and integration of the δ 4.55 C_4-methylene proton of **32** *vs.* the C_2 proton of **33** gave the **32:33** ratio of 1:3.

Reaction of **31** and **18** in tetrahydrofuran at 25° gave an orange solution. The nmr spectrum was recorded (Table III), and integration of the C_1 and C_3 protons of **32** *vs.* those of **33** showed that these two anions were produced in a **32:33** ratio of 1:3, the same ratio as that found from the reaction of **31** and **27**.

As was pointed out in the previous section, **3** appeared to add exclusively to 6-methylazulene in ether solvent, but in tetrahydrofuran this reaction resulted in proton ab-

straction from the methyl group to yield lithium 6-methyleneazulenate. The latter reaction mode was also apparently followed in the reaction of 4-methylazulene and 3 in tetrahydrofuran producing lithium 4-methyleneazulenate.

However, when 15 was allowed to react with hydrocarbon 31, no evidence for methyl group proton abstraction was found; instead the products of nucleophilic addition were observed (see Table II). The nmr spectrum of the yellow solution resulting from reaction of 15 and 31 in tetrahydrofuran at 25° was interpreted as that of a mixture of lithium 4,6,8-trimethyl-4-dimethylaminoazulenate (34) and lithium 4,6,8-trimethyl-6-dimethylaminoazulenate (35). Integration of the C_7 and C_2 protons of 34 and 35, respectively, gave a 34:35 ratio of 3:1. The relative

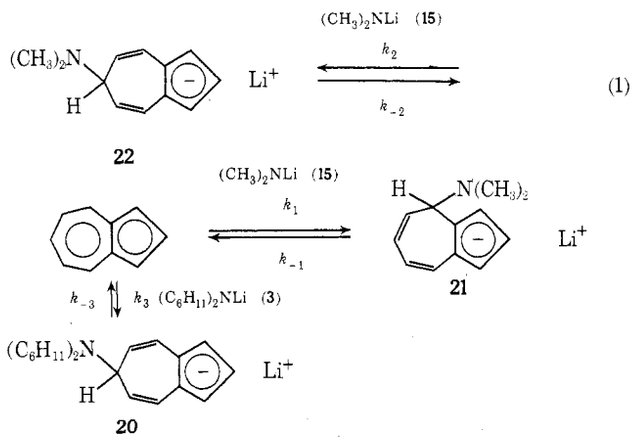


34 35

amount of 35 increased as a function of time when the sample was maintained at 25° as seen in the changes in the 34:35 ratio: 15 min, 3:2, 30 min, 1:1; and 3 hr, 3:7. No signals for anions 32 or 33 were observed.

Discussion

Reactions with Nitrogen Bases. The temperature dependency of the product compositions from the addition reactions of azulene and trimethylazulene 31 with 15 suggests that the ring C_4 position was the site of kinetically controlled nucleophilic addition while addition to the ring C_6 position led to the product of thermodynamic control. The mechanism by which the Meisenheimer type complexes 21 and 22 (34 and 35) are equilibrated (K_1 and K_2) might involve a small (unobservable by nmr) concentration of azulene present in the mixture or an S_N2' type of displacement on 21 or 22 by external nucleophile. The latter mechanistic possibility, however, would require an ionic attack on an anion and is believed to be less likely than the former suggested mechanism involving free azulene.



Although a similar equilibrium between azulene + 3 ⇌ 20 could not be established directly, the results of the following experiment lead us to conclude that k_{-3} is present. Equivalent amounts of azulene and 3 in tetrahydrofuran were mixed at 33° and the nmr spectrum was recorded, showing the presence of 20 along with a small amount of unreacted azulene. To this solution was added an equivalent amount of 15 in tetrahydrofuran at −10°. The nmr spectrum was immediately recorded and revealed the presence of a new pair of doublets at δ 6.71 and 6.65 attributed to 21 and 22. While it was not possible to accurately determine the relative amounts of 20, 21, and 22 owing to overlapping absorptions, the spectra showed that the amount of 20 decreased and 21 and 22 concentrations increased on standing at −10°. After 1 hr at −10° only a trace of 20 could be observed.

Accepting our proposed mechanism for the formation and equilibration of 20–22, the above result says that K_1 and K_2 are larger than K_3 by factors of 20–100. This is qualitatively the same conclusion reached from considering the equivalents of base needed to completely react with azulene. This probably reflects the increased steric size of the cyclohexyl groups in 20 compared to methyl groups in 22. However, we presently have no direct way of knowing if this influences only the forward (k_1, k_2, and k_3) or reverse (k_{-1}, k_{-2}, and k_{-3}) steps, or both. This also gives no information of the relative magnitudes of forward and reverse rate constants involved in yielding 20–22 except that we know that $k_1 > k_2$ from equilibration studies. From the observations that both nitrogen nucleophiles, 3 and 15, "immediately" decolorized azulene solutions with rapid mixing we know that k_1, k_2, and k_3 are large bimolecular rate constants. Assuming a steric effect in the additions of 3 and 15 to the azulene ring 4 and 6 positions we would expect $k_1 > k_2 > k_3$.

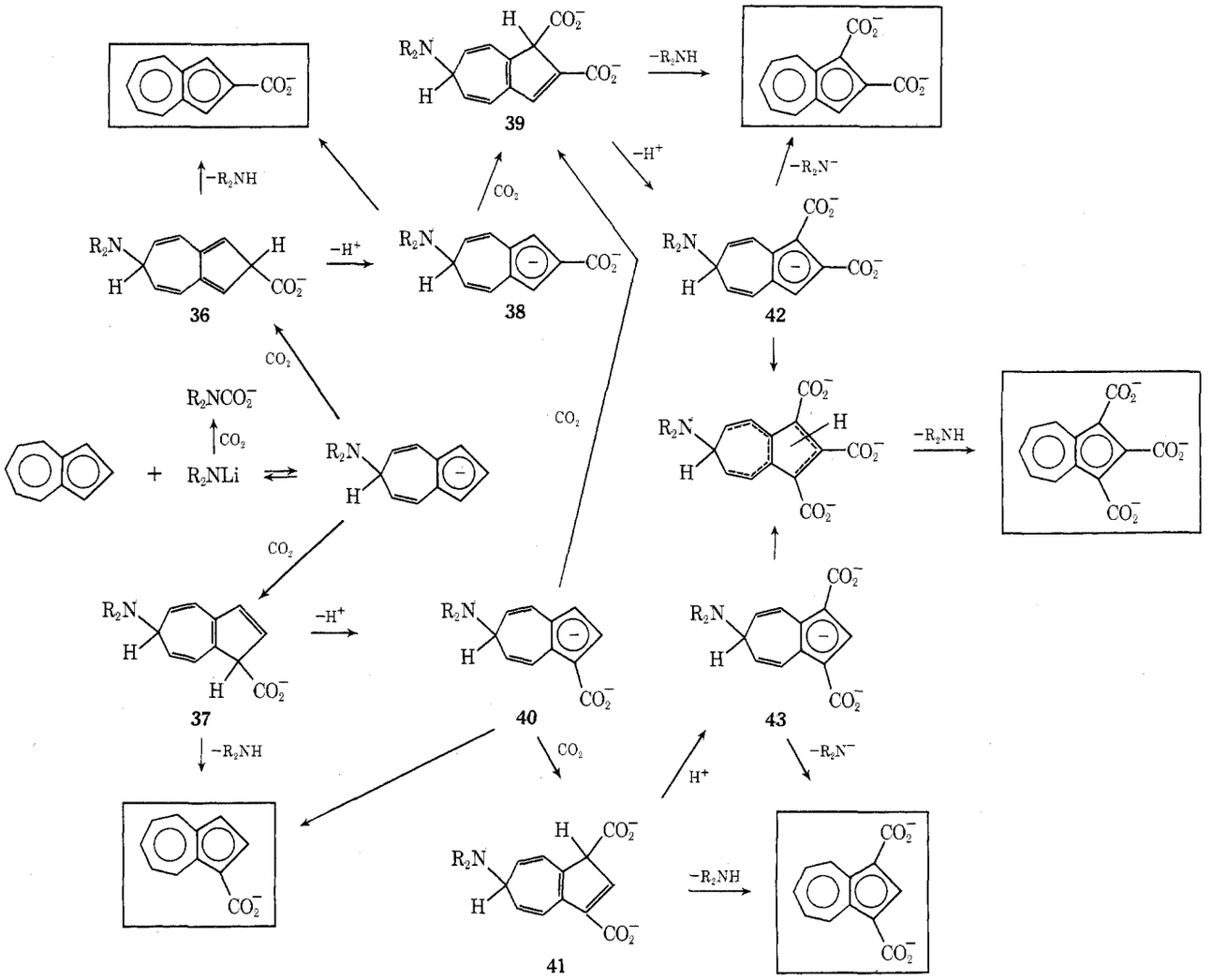
Qualitatively, there appears to be a definite difference in the rates of reaction of 3 and 15 with carbon dioxide. Bubbling carbon dioxide into a solution of 15 in ether resulted in immediate formation of a white precipitate, probably lithium dimethylcarbamate. Similar treatment of an ether solution of 3 required 30–40 sec before a precipitate was observed which slowly increased in amount. Ignoring any gross solubility differences in the two salts, we take this to mean that 15 reacts considerably faster with carbon dioxide than does 3.

Having identified the products from the reaction of azulene and 3 and 15 as Meisenheimer-type complexes 20, and 21 and 22, we can proceed to discuss the suspected processes resulting in the formation of the nuclear carbonation products from reaction of 20 with carbon dioxide as well as reasons why related results fail to occur on carbonation of 21 and 22. The proposed pathways leading from 20 to the five nuclear carbonation products 10–14 are given in Scheme I. Carbonation of 20 leading to the monocarboxylated products (10 and 13) involving loss of the elements of dicyclohexylamine from their respective intermediates, 36 and 37, is straightforward. However, to form the di- and tricarboxylated products we believe requires that the loss of a proton from 36 and 37 (39 and 41) yielding cyclopentadienidecarboxylates 38 and 40 (42 and 43) must compete with total loss of the amine. Intermediates 38, 40, 42, and 43 may also eject dicyclohexylamide to yield their respective carboxylic acid salts.

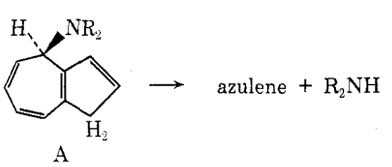
In each of the reactions of 5- and 6-methylazulene and azulene with 3 followed by reaction with carbon dioxide, substantial amounts of the starting azulene were recovered even though the azulene had been totally (by nmr) converted to its Meisenheimer-type complex prior to carbonation. This might result in at least three ways: (1) competitive carbonation of 3 in equilibrium with the azulene, (2) carbonation at a bridgehead center with that product reverting to the azulene during work-up, and/or (3) a ready proton exchange between the initially formed adduct and the carbonation products generating anions such as 38 and 40 and A.[21]

While we believe that this mechanistic scheme accounts for the variety of products derived from carbonation of 20, we must now deal with the fact that *only* starting azulene is found (generally 90+%) when mixtures of 21 and 22 and 34

Scheme I
Mechanistic Pathways for Formation of the Five Nuclear Carbonation Products from Azulene[a]



[a] For convenience the cations have been omitted.



A

and **35** are carbonated. Since the rates of five-membered ring carbonation of **20** and **22** should be approximately the same, the reason for the anomalous behavior of **22** must then lie in the relative rates of previous steps. We suggest that the explanation may be in the rates defined by k_{-1} and k_{-2} being at least equal to but probably greater than k_{-3} in eq 1. Taken together with the apparently much faster rate of reaction of carbonation of **15** compared to **3** could then account for the observed results. If this is correct then k_2 must be much greater than k_3 in general agreement with the analysis of k_1, k_2, and k_3 given above. This may simply reflect solvation energy differences in the amides **3** and **15**, and their respective adducts **20**, and **21** and **22**.

It is again interesting to note the solvent effect in the type of reaction product from 6-methylazulene and **3**; in ether ring addition was observed while in tetrahydrofuran proton abstraction exclusively took place. When the amide is the dimethyl derivative **15** and it was allowed to react with 4,6,8-trimethylazulene (**31**) in tetrahydrofuran only the products (**34** and **35**) of addition to the ring were observed in the nmr spectrum. These results appear to demonstrate the better nucleophilic *vs.* basic character of **15** in these reactions compared to **3**. A probable major factor in this increased ease of nucleophilic addition by **15** is the much larger steric requirements for nucleophilic attack at the ring sites by **3**.

Reactions with Carbon Bases. In marked contrast with the results of the nitrogen bases, when the carbon bases (**18**, **23**, and **27**) added to the 4 and/or 6 positions of the azulene ring the products were thermally stable and in the case with **23** the product mixture was invariant over the addition temperature range investigated. If we accept the premise that these product distributions are formed under kinetic control, such studies with carbon nucleophiles of varying structure could give a clear relationship between the steric size of the nucleophile and the $\Delta\Delta F^{*}$'s for attack at the two ring positions. The extreme with the bulky nucleophile, **18**, is to yield exclusive addition to the 6 position while with the small nucleophiles, **23** and **27**, the preference (9:1) is to add to the ring 4 position. Thus with both carbon (kinetic) and nitrogen (kinetic and thermodynamic) nucleophiles, steric bulk of the attacking base is important in determining the ring position to be attacked.

As was the case with the nitrogen bases, the carbon bases show different nucleophilic *vs.* basic characters. Hafner[19] reported that **23** added to 4-methylazulene and

after protonation and dehydrogenation the product 4,8-dimethylazulene was isolated in 52% yield. However, the reaction between **31** and **18** or **27** yields only the products of proton abstraction from the methyl groups.[5a] The dynamics involved with the carbon nucleophiles, however, were not as well investigated as were those with the nitrogen bases.

Experimental Section[22]

Lithium Dicyclohexylamide (3). Using a dry syringe, 4.39 g (0.0242 mol) of twice-distilled dicyclohexylamine was injected into a flame-dried three-necked flask containing 25 ml of dry ether (distilled from $LiAlH_4$) under a nitrogen atmosphere. With continous stirring, the solution was cooled to −20° and 20 ml of a 1.22 *M* solution of methyllithium in ether was slowly injected into the solution (vigorous bubbling). The solution was allowed to stir for 0.5 hr as the solution warmed to room temperature. Titration of two aliquots of this solution with standard hydrochloric acid indicated the solution to be 0.519 *M* in amide.

Solutions of lithium dimethylamide (**15**) were prepared by this method also.

Reaction of 3 with 5-Methylazulene Followed by Carbonation and Methylation. To a flame-dried flask under a nitrogen atmosphere was added 426 mg (3.00 mmol) of 5-methylazulene in 10 ml of dry ether. The contents of the flask were cooled to −20° and 5.70 ml of the 0.519 *M* **3** solution was slowly injected into the solution by means of a syringe. With stirring the solution was allowed to come to room temperature over 20 min with no visible color change. Dry carbon dioxide (passed through sulfuric acid and Na_2CO_3–Drierite) was bubbled through the solution for 0.5 hr with the formation of a red-violet precipitate in the flask. The reaction mixture was diluted with 50 ml of cold 5% aqueous sodium hydroxide and extracted with ether. The ether layer containing unreacted 5-methylazulene was washed with six 50-ml portions of 5% aqueous sodium hydroxide, water, two 100-ml portions of 10% hydrochloric acid, and water. The ether layer was dried ($MgSO_4$), the solvent volume was reduced, and the residue was chromatographed on 50 g of basic alumina with 9:1 hexane–dichloromethane to yield 0.255 g of 5-methylazulene.

The sodium hydroxide solutions were combined, acidified, and extracted with 250 ml of ether. This ether layer was washed with water and dried ($MgSO_4$). To this solution was added an excess of an ether solution of diazomethane. After standing for 5 min, the ether layer was washed with two 100-ml portions of 5% aqueous sodium bicarbonate and water and dried ($MgSO_4$). After solvent reduction, the products were chromatographed on 70 g of basic alumina.

CCl_4–CH_2Cl_2 (3:1) eluted a violet band containing 102 mg (17%, 42.3% net) of a mixture of methyl 5- and 7-methyl-1-azulenecarboxylate (**4**) as a violet oil: ir (film) 5.91 μ (s, C=O); nmr (CCl_4, internal TMS) τ 0.36 (broad s, 0.7), 0.46 (d, 0.3), 1.71–3.00 (m, 5), 6.11 (s, CO_2CH_3, 3), 7.25 (s, CH_3, 0.7), 7.35 (s, CH_3, 0.3); visible-uv (cyclohexane) 657 nm (log ε 2.23), 598 (2.61), 552 (2.65), 372 (4.03), 358 (3.87), 342 (3.86), 301 (4.71), 290 (4.65), and 240 (4.32).

Anal. Calcd for $C_{13}H_{12}O_2$: C, 77.98; H, 6.04. Found: C, 78.20; H, 5.92.

CCl_4–CH_2Cl_2 (1:1) eluted a red band containing 19 mg (2.2%, 5.5% net) of a red oil identified as dimethyl 5-methyl-1,3-azulenedicarboxylate (**5**) on the basis of its visible spectrum (cyclohexane): 606 (O.D. 0.361), 554 (0.902), and 519 nm (0.978).

A violet-blue band was eluted with CCl_4–CH_2Cl_2 (1:3) containing 7 mg (0.9%, 2.3% net) of a mixture of dimethyl 5- and 7-methyl-1,2-azulenedicarboxylate (**6**) as a violet-blue oil based on the visible-uv spectra: ir (film) 5.83 (s, C=O) and 5.94 μ (s, C=O); visible-uv (cyclohexane) 588 nm (log ε 2.64), 368 (3.61), 350 (3.68), 303 (4.60), 293 (4.57), and 242 (4.35).

Reaction of 3 with 6-Methylazulene Followed by Carbonation and Methylation. Using the above procedure, 426 mg (3.00 mmol) of 6-methylazulene was allowed to react with 5.70 ml (2.95 mmol) of 0.519 *M* **3**. Upon warming to −10°, the color of the solution changed to yellow-black. To the solution was added an additional 25 ml of dry ether and dry carbon dioxide was bubbled through the solution at a moderate rate for 0.5 hr. From the base-insoluble fraction was recovered 315 mg of 6-methylazulene.

The acids were methylated with diazomethane and chromatographed on 70 g of basic alumina. CCl_4–CH_2Cl_2 (3:1) eluted a violet band containing 50 mg (8.3%, 32% net) of methyl 6-methyl-1-azulenecarboxylate (**7**) as red-violet prisms: mp 77–79°; ir (KBr) 5.92 μ (s, C=O); nmr (CCl_4, internal TMS) τ 0.54 (d, *J* = 10.0 Hz, C_8 H, 1), 1.81 (d, *J* = 10.0 Hz, C_4 H, 1), 1.85 (d, *J* = 4.0 Hz, 1), 2.50–3.00 (m, 3), 6.11 (s, CO_2CH_3, 3), and 7.36 (s, CH_3, 3); visible-uv (cyclohexane) 629 nm (log ε 2.17), 601 (2.22), 573 (2.56), 547 (2.57), 531 (2.61), 370 (4.02), 355 (3.89), 344 (3.85), 304 (4.81), 297 (4.71), 292 (4.72), 262 (3.87), 255 (3.96), and 235 (4.34); mass spectrum (70 eV, heated inlet) *m/e* (rel intensity) 200 ($M^{\cdot+}$, 58) and 169 (100).

Anal. Calcd for $C_{13}H_{12}O_2$: C, 77.98; H, 6.04. Found: C, 78.00; H, 6.30.

CCl_4–CH_2Cl_2 (1:1) eluted a blue band containing 20 mg (3.3%, 13% net) of blue plates, mp 108–110°, of methyl 6-methyl-2-azulenecarboxylate (**8**) based on spectral evidence: ir (KBr) 5.86 μ (s, C=O); nmr (CCl_4, internal TMS) τ 1.77 (d, *J* = 10.5 Hz, C_4 and C_8 H, 2), 2.34 (s, C_1 and C_3 H, 2), 2.96 (d, *J* = 10.5 Hz, C_5 and C_7 H, 2), 6.08 (s, CO_2CH_3, 3), and 7.35 (s, CH_3, 3); visible-uv (cyclohexane) 704 nm (log ε 2.23), 694 (2.19), 637 (2.53), 592 (2.52), 362 (3.85), 348 (3.73), 336 (3.67), 296 (4.72), 285 (4.75), 266 (4.20), and 240 (4.17); mass spectrum (70 eV, heated inlet) *m/e* (rel intensity) 200 ($M^{\cdot+}$, 64) and 169 (100).

A second violet band was eluted with CCl_4–CH_2Cl_2 (1:3) and contained 39 mg (5.0%, 19% net) of violet needles, mp 69–71°, of dimethyl 6-methyl-1,2-azulenedicarboxylate (**9**) based on spectral evidence: ir (KBr) 5.80 (s, C=O) and 5.91 μ (s, C=O); nmr (CCl_4, internal TMS) τ 0.80 (d, *J* = 10.5 Hz, C_8 H, 1), 1.79 (d, *J* = 10.5 Hz, C_4 H, 1), 2.50–2.90 (m, 3), 6.10 (s, CO_2CH_3, 3), 6.11 (s, CO_2CH_3, 3), and 7.84 (s, CH_3, 3); visible-uv (cyclohexane) 563 nm (log ε 2.67), 368 (3.62), 352 (3.77), 305 (4.78), 294 (4.72), and 423 (4.26); mass spectrum (70 eV, heated inlet) *m/e* (rel intensity) 258 ($M^{\cdot+}$, 61), 227 (100), 200 (9), and 197 (12).

Reaction of 3 with Azulene Followed by Carbonation and Methylation. A. In Ether. Following the above procedure, 384 mg (3.0 mmol) of azulene in 10 ml of ether was allowed to react with 5.70 ml (2.95 mmol) of a 0.519 *M* ether solution of **3** at −20°. The solution was warmed to room temperature with no visible color change. Dry carbon dioxide was bubbled through the solution for 0.5 hr. From the base-insoluble fraction 310 mg of azulene was obtained.

The acids were methylated with diazomethane and chromatographed on 70 g of basic alumina. CCl_4–CH_2Cl_2 (3:1) eluted a violet band containing 76 mg (14%, 71% net) of methyl 1-azulenecarboxylate (**10**) as violet needles: mp 54–55° (lit.[10a] mp 56–57°); ir (KBr) 5.93 μ (s, C=O); nmr (CCl_4, internal TMS) τ 0.30 (broad d, C_8 H, 1), 1.62 and 1.70 (two superimposed d, 2), 2.00 and 2.80 (m, 4), and 6.10 (s, CO_2CH_3, 3); visible-uv (cyclohexane) 645 nm (log ε 2.19), 612 (2.21), 588 (2.55), 561 (2.54), 542 (2.60), 368 (4.04), 350 (4.03), 338 (3.96), 298 (4.78), 292 (4.68), 286 (4.69), 255 (3.88), 249 (4.03), and 236 (4.35).

CCl_4–CH_2Cl_2 (1:1) eluted a red band containing 17 mg (2.3%, 12% net) of red needles of dimethyl azulene-1,3-dicarboxylate (**11**): mp 171–173° (lit.[23] mp 171°); ir (KBr) 5.89 μ (s, C=O); nmr ($CDCl_3$, internal TMS) τ 0.05 (broad d, C_4 and C_8 H, 2), 1.07 (s, C_2 H, 1), 2.12 (m, 3), and 6.02 (s, CO_2CH_3, 3); visible-uv (cyclohexane) 598 nm (log ε 2.21), 547 (2.64), 511 (2.70), 374 (4.03), 370 (4.05), 366 (3.99), 361 (4.00), 330 (3.71), 303 (4.71), 296 (4.60), 292 (4.58), 268 (4.52), 263 (4.40), 249 (4.15), and 235 (4.63).

A second violet band was eluted with CCl_4–CH_2Cl_2 (1:3) containing 10 mg (1.4%, 7% net) of dimethyl 1,2-azulenedicarboxylate (**12**) as a violet oil: ir (film) 5.80 (s, C=O) and 5.91 μ (s, C=O); nmr (CCl_4, internal TMS) τ 0.55 (broad d, C_8 H, 1), 1.55 (broad d, C_4 H, 1), 1.98–2.80 (m, 4), and 6.06 and 6.07 (two overlapping s, CO_2CH_3, 6); visible-uv (cyclohexane) 578 nm (log ε 2.66), 364 (3.68), 347 (3.85), 300 (4.72), 290 (4.69), and 238 (4.35).

Anal. Calcd for $C_{14}H_{12}O_4$: C, 68.84; H, 4.95. Found: C, 68.95; H, 5.21.

B. In Tetrahydrofuran. To a solution of 750 mg (5.9 mmol) of azulene in 10 ml of dry tetrahydrofuran (distilled from $LiAlH_4$) cooled to −30° under a nitrogen atmosphere was added 5.9 ml (5.9 mmol) of 1 *M* **3** in tetrahydrofuran. There was no apparent color change and the solution was warmed to 25°, where it took on a green cast. Carbon dioxide was bubbled in and produced a blue solution. Carbon dioxide addition was continued for 10 min and then 100 ml of water was added which produced effervescence. An additional 400 ml of water and 100 ml of 10% potassium hydroxide were added and the basic solution was extracted with three 100-ml portions of ether. The ether layer was acidified with 10% hydrochloric acid and dicyclohexylamine hydrochloride precipitated. This white precipitate was filtered, and the ethereal filtrate was washed with three 100-ml portions of water and dried ($MgSO_4$). Concentration of the solvent followed by chromatogra-

phy on basic, activated alumina gave on elution with carbon tetrachloride 389 mg (52%) of starting azulene.

The violet, basic solution was acidified with cold 20% hydrochloric acid and extracted with 900 ml of ether. The violet ether solution was washed with three 100-ml portions of water and dried ($MgSO_4$). The carboxylic acids were converted to their methyl esters using diazomethane in ether and chromatographed on neutral activity II Woelm alumina.[24] CCl_4 eluted 122 mg (11%, 23% net) of methyl 1-azulenecarboxylate (**10**), mp 54–55°, followed by 51 mg (5%, 10% net) of methyl 2-azulenecarboxylate (**13**): mp 109–110° (lit.[25] mp 110–111°); ir (KBr) 5.82 μ (C=O); nmr ($CDCl_3$, internal TMS) τ 1.4–3.2 (m, Az H's, 7) and 6.03 (s, CH_3); visible-uv (cyclohexane) 724 nm (log ϵ 2.35), 654 (2.68), 605 (2.66), 356 (3.52), 344 (3.72), 330 (3.63), and 284 (4.72). Elution with CCl_4–CH_2Cl_2 (3:1) gave 53 mg (4%, 8% net) of dimethyl 1,3-azulenedicarboxylate (**11**), mp 174.5–176°. With CCl_4–CH_2Cl_2 (1:1), 76 mg (5%, 11% net) of dimethyl 1,2-azulenedicarboxylate (**12**) was eluted which crystallized; recrystallization from hexane gave violet-blue crystals, mp 46.5–47.5° (lit.[26] oil). Elution with CH_2Cl_2 gave 14 mg (1%, 2% net) of trimethyl 1,2,3-azulenetricarboxylate (**14**), which was recrystallized from CH_2Cl_2–petroleum ether to give red crystals: mp 155–156°; ir (KBr) 5.73 (C=O) and 5.92 μ (C=O); nmr ($CDCl_3$, internal TMS) τ 0.0–2.4 (m, Az H's, 5), 5.97 (s, CH_3, 3), and 6.07 (s, CH_3, 6); visible-uv (CH_2Cl_2) 500 nm (log ϵ 2.83), 368 (3.75), 335 (3.74), 304 (4.64), 294 (sh), and 272 (4.42).

Anal. Calcd for $C_{16}H_{14}O_6$: C, 63.58; H, 4.67. Found: C, 63.41; H, 4.53.

Reaction of Azulene with 15 in Tetrahydrofuran and Quenching with Methanol. To 200 mg (1.56 mmol) of azulene dissolved in 5 ml of dry tetrahydrofuran (distilled from $LiAlH_4$) under a nitrogen atmosphere and cooled to 0° was added 70 mg of dimethylamine in 5 ml of dry tetrahydrofuran followed by 1 ml (1.5 mmol) of 1.5 *M* methyllithium in ether dropwise. The solution turned from blue to yellow with the addition of the final drops of methyllithium. After cooling to −70°, 0.1 ml of absolute methanol was added, at which time the yellow solution was washed with three 100-ml portions of water and dried ($MgSO_4$). Evaporation of the solvent gave 195 mg (98%) of starting azulene.

Reaction of Azulene with 15 in Tetrahydrofuran Followed by Addition of Carbon Dioxide. To a solution of 100 mg (0.78 mmol) of azulene dissolved in 10 ml of dry tetrahydrofuran (distilled from $LiAlH_4$) under a nitrogen atmosphere and cooled to −30° was added 0.78 ml (0.78 mmol) of 1 *M* lithium dimethylamide in tetrahydrofuran. The solution immediately turned light green and was allowed to warm to room temperature. Carbon dioxide was bubbled into the solution, which turned blue. Carbon dioxide addition was continued for 10 min followed by the addition of 100 ml of water, which produced effervescence; 10 ml of 10% potassium hydroxide and 100 ml of ether were added. The ether layer was separated and washed with three 100-ml portions of water and dried ($MgSO_4$). Chromatography over basic alumina on elution with CCl_4 gave 94 mg (94%) of starting azulene.

Reaction of 4-Methylazulene with 15 Followed by Addition of Carbon Dioxide. This reaction was carried out as described above starting with 100 mg (0.70 mmol) of 4-methylazulene, 2 ml of dry tetrahydrofuran (distilled from $LiAlH_4$), and 2 ml (1.20 mmol) of 0.60 *M* lithium dimethylamide in tetrahydrofuran at −70°. The yellow solution was diluted with 10 ml of ether and allowed to warm to 25°. With the addition of carbon dioxide, which was continued for 10 min, the solution turned blue and a white precipitate formed. The addition of 100 ml of water produced effervescence and the white precipitate dissolved. Ether (100 ml) was added, and the colorless, basic, aqueous layer separated. Work-up as above gave 93 mg (93%) of starting 4-methylazulene.

When this reaction was carried out in tetrahydrofuran or benzene as solvent, the recoveries of 4-methylazulene were 87 and 92%, respectively.

Reaction of Azulene with 15 Followed by Oxidation with Oxygen. To a solution of 200 mg (1.56 mmol) of azulene in 5 ml of dry tetrahydrofuran under a nitrogen atmosphere and cooled to −70° was added 2.6 ml (1.6 mmol) of 0.60 *M* lithium dimethylamide in tetrahydrofuran. The color changed from blue to light green with the addition of the base. Oxygen was bubbled into this solution at −70° for 5 min but no color change was noted. The solution was allowed to warm to 25° and oxygen addition was continued for 20 min. To the reaction mixture was added 100 ml of water and 100 ml of ether. The ether layer was separated, washed with three 100-ml portions of water, and dried (Na_2SO_4). Chromatography over basic, activity I–II alumina[24] gave on elution with carbon tetrachloride 83 mg (42%) of starting azulene. Continued elution with carbon tetrachloride gave 21 mg (8%, net 13.5%) of 4-*N*,*N*-dimethylaminoazulene (**16**) as an unstable purple oil: ir (neat film) 3.51 (CH), 6.47, 7.46, and 10.93 μ; nmr ($CDCl_3$, internal TMS) τ 1.8–3.7 (m, Az H's, 7), 6.72 (s, CH_3, 6); visible-uv (cyclohexane) 715 nm (log ϵ 1.17), 546 (2.59), 308 (4.05), and 274 (4.51).

Anal. Calcd for $C_{12}H_{13}N$: C, 84.15; H, 7.67. Found: C, 84.31; H, 7.56.

Elution with methylene chloride gave 33 mg (12%, net 21.3%) of 6-*N*,*N*-dimethylaminoazulene (**17**) as a yellow solid: mp 169–170° (lit.[12] mp 163–164.5°); ir (KBr) 3.50, 6.35, 7.38, and 12.20 μ; nmr ($CDCl_3$, internal TMS) τ 1.8–3.7 (m, Az H's, 7) and 6.81 (s, CH_3, 6); visible-uv (cyclohexane) 505 nm (log ϵ 2.59), 486 (2.60), 475 (sh), 390 (4.72), 382 (4.61), and 316 nm (4.79).

When the above reaction of azulene (100 mg) and **15** was carried out at −70°, the mixture allowed to warm to room temperature, and then the oxygen bubbled into the solution, work-up gave a trace of recovered azulene, 9 mg (7%) of **16**, and 18 mg (14%) of **17**. Using chloranil in place of oxygen in this sequence gave only 15 mg (11%) of **16** as a pure product.

Reaction of 4,6,8-Trimethylazulene (31) and 15 in Tetrahydrofuran Followed by Addition of Carbon Dioxide. This reaction was carried out as described above starting with 200 mg (1.18 mmol) of 4,6,8-trimethylazulene in 10 ml of dry tetrahydrofuran at −70°. With the addition of 3.90 ml (2.34 mmol) of 0.60 *M* lithium dimethylamide in tetrahydrofuran the solution turned from purple to yellow. The solution was warmed to 25° and addition of carbon dioxide for 10 min gave a purple solution. Addition of 50 ml of water and extraction with 50 ml of ether left a colorless, basic, aqueous solution. Work-up of the ether layer gave on chromatographic elution with carbon tetrachloride 168 mg (84%) of the starting 4,6,8-trimethylazulene.

When the above reaction mixture was quenched with water, 97% of the starting 4,6,8-trimethylazulene was recovered.

Reaction of Azulene and Tritylsodium. To a solution of 100 mg (0.78 mmol) of azulene dissolved in 10 ml of dry tetrahydrofuran (distilled from $LiAlH_4$) under a nitrogen atmosphere was added 1.5 ml of an approximately 0.7 *M* solution of tritylsodium in ether. To the resulting orange solution cooled to −70° were added 1 ml of absolute methanol and 1 g of chloranil. The mixture was diluted with 100 ml of ether and stirred at 25° for 24 hr. The excess chloranil was removed by filtration and the ether solution was washed with water and dried ($MgSO_4$). The solvent was concentrated and the residue was chromatographed over basic, activated alumina, where elution with carbon tetrachloride gave a blue oil. On standing in ether a white precipitate formed and was filtered. The filtrate was concentrated and crystallization from carbon tetrachloride–petroleum ether gave a blue solid which could not be purified by further crystallization or repeated chromatography: mp 205–215°; ir (KBr) 6.41, 6.76, 7.09, and 7.35 μ; nmr (CCl_4, internal TMS) τ 1.90 (d, C_4 and C_8 H, 2), 2.1–3.2 (m, Az H's and phenyl H's, integrated for 19 instead of 20); visible-uv (cyclohexane) 696 nm (O.D. 0.120), 658 (0.138), 632 (0.276), 604 (0.278), 579 (0.035), 557 (0.254), 348 (0.102), 341 (0.098), 333 (0.092), 299 (0.979), 289 (0.885), and 284 (0.923); mass spectrum (70 eV) *m/e* (rel intensity) 370 ($M^{\cdot+}$, 50), 243 (241), and 127 (11).

It was noted that on standing in petroleum ether in the light or in the dark at −20° a white precipitate formed in a period of several days. The solution showed no color change.

Reaction of 6-Methylazulene and 3 in Tetrahydrofuran Followed by Addition of Carbon Dioxide. Following the procedure described above, 200 mg (1.41 mmol) of 6-methylazulene and 1.41 ml (1.41 mmol) of 1 *M* lithium dicyclohexylamide in tetrahydrofuran were added to 10 ml of dry tetrahydrofuran at −30° and the golden-colored solution was warmed to 25°. Carbon dioxide addition and the same work-up as described above gave 71 mg (36%) of recovered 6-methylazulene and 103 mg (39%) of 6-azulylacetic acid.[3]

Reaction of 4-Methylazulene with 3 in Tetrahydrofuran Followed by Addition of Carbon Dioxide. A solution of 274 mg (1.93 mmol) of 4-methylazulene in 10 ml of dry tetrahydrofuran (distilled from $LiAlH_4$) under a nitrogen atmosphere was cooled to −30°. When 1.93 ml (1.93 mmol) of 1 *M* lithium dicyclohexylamide was added the solution turned yellow. After warming to 25° carbon dioxide was added for 10 min; the initial addition produced a blue solution. To this was added 100 ml of water and 20 ml of 10% potassium hydroxide. The basic, aqueous layer was washed with two 100-ml portions of ether. The combined ether layers were worked up as described above to yield 59 mg (22%) of starting 4-methylazulene.

The aqueous, basic layer was acidified with 10% hydrochloric acid and extracted with three 100-ml portions of ether. Concentration gave 252 mg (70%) of 4-azulylacetic acid.[3]

Reaction of 4,6,8-Trimethylazulene and 3 Followed by Addition of Carbon Dioxide at 25°. Following the procedure described previously, 100 mg (0.59 mmol) of 4,6,8-trimethylazulene in 10 ml of dry tetrahydrofuran cooled to −50° was allowed to react with 0.59 ml (0.59 mmol) of 1 *M* lithium dicyclohexylamide in tetrahydrofuran and the solution turned brown. It was then allowed to warm up to 25° and stirred for 1 hr before carbon dioxide was added. The reaction mixture was worked up as described above and gave 16 mg (16%) of the starting 4,6,8-trimethylazulene and 99 mg (79%) of a mixture of acids. The acid mixture, as determined by nmr integration of the methylene protons, consisted of 45% 6,8-dimethyl-4-azulylacetic acid and 55% 4,8-dimethyl-6-azulylacetic acid.

The reaction was repeated with carbonation at −30° and gave a 65% yield of a mixture of acids which consisted of 44% 6,8-dimethyl-4-azulylacetic acid and 56% 4,8-dimethyl-6-azulylacetic acid.

The reaction was repeated with carbonation at −70° and gave a 43% yield of a mixture of acids consisting of 47% 6,8-dimethyl-4-azulylacetic acid and 53% 4,8-dimethyl-6-azulylacetic acid.

Reaction of 4,6,8-Trimethylazulene and Sodium *N*-Methylanilide in Tetrahydrofuran Followed by Addition of Carbon Dioxide at −10°. The reaction was carried out as described earlier starting with 100 mg (0.59 mmol) of 4,6,8-trimethylazulene in 50 ml of dry tetrahydrofuran cooled to −15°. To this was added 0.61 ml (0.59 mmol) of 0.97 *M* sodium *N*-methylanilide in tetrahydrofuran. The solution turned a golden color on warming to −10°. Carbon dioxide was bubbled in for 10 min, which immediately caused the solution to turn purple. Work-up as described earlier gave 112 mg (89%) of a mixture of 6,8-dimethyl-4-azulylacetic acid and 4,8-dimethyl-6-azulylacetic acid. Integration of the nmr spectrum of this mixture for the C_4 and C_6 methylene protons showed the mixture to be composed of 68 and 32%, respectively, of these two acids.

Reaction of 4,6,8-Trimethylazulene and Tritylsodium in Ether. Following the procedure outlined above, 100 mg (0.59 mmol) of 4,6,8-trimethylazulene in 10 ml of ether cooled to −15° was allowed to react with 2.2 ml of approximately 0.5 *M* tritylsodium (excess) in ether. The addition of carbon dioxide at 0° and work-up gave only base-soluble material. The acids were converted to their methyl esters and analysis of the nmr spectrum indicated that the mixture contained methyl 6,8-dimethyl-4-azulylacetate, methyl 4,8-dimethyl-6-azulylacetate, and methyl triphenylacetate: nmr (CCl_4, internal TMS) τ 2.2–3.1 (m, Ar and Az H's), 5.95–6.38 (group of singlets which are α-methylene and ester methyl protons), and 7.19–7.39 (three singlets, Az methyls).

Acknowledgments. The authors wish to thank the National Science Foundation for support of this research (GP-7818, GP-10691 granted to R. N. M.) and instrument grants for the nmr (T-60 and XL-100) and mass spectrometers used in this study and the Phillips Petroleum Co. for a fellowship to H. E. Petty (1968–1969).

Registry No.—**1**, 51381-34-1; **3**, 4111-55-1; 4 (5-methyl), 51381-35-2; 4 (7-methyl), 51381-36-3; **5**, 51381-37-4; 6 (5-methyl), 51381-38-5; 6 (7-methyl), 51381-39-6; **7**, 51381-40-9; **8**, 51381-41-0; **9**, 51381-42-1; **10**, 14659-03-1; **11**, 51381-43-2; **12**, 39479-45-3; **13**, 14658-96-9; **14**, 51381-44-3; **15**, 3585-33-9; **16**, 51381-45-4; **17**, 2048-68-2; **18**, 4303-71-3; **20**, 51381-46-5; **21**, 51381-47-6; **22**, 51381-48-7; **23**, 917-54-4; **24**, 51381-49-8; **25**, 51381-50-1; **26**, 51381-51-2; **27**, 51464-52-9; **28**, 51381-52-3; **29**, 51381-53-4; **30**, 5000-15-7; **31**, 941-81-1; **32**, 51381-54-5; **33**, 51381-55-6; **34**, 51381-56-7; **35**, 51381-57-8; azulene, 275-51-4; 5-methylazulene, 1654-55-3; 6-methylazulene, 1654-52-0; 4-methylazulene, 17647-77-7; methyl 6,8-dimethyl-4-azulylacetate, 26157-18-6; methyl 4,8-dimethyl-6-azulenylacetate, 51381-58-9; methyl triphenylacetate, 5467-21-0.

References and Notes

(1) (a) For paper IX in this series see R. G. Cooks, R. N. McDonald, P. T. Cranor, H. E. Petty, and N. L. Wolfe, *J. Org. Chem.*, **38**, 1114 (1973). (b) Phillips Petroleum Co. Fellowship, 1968–1969.
(2) R. N. McDonald and J. R. Curtis, *J. Amer. Chem. Soc.*, **93**, 2530 (1971).
(3) R. N. McDonald, N. L. Wolfe, and H. E. Petty, *J. Org. Chem.*, **38**, 1106 (1973).
(4) (a) A. G. Anderson, R. G. Anderson, and T. S. Fujita, *J. Org. Chem.*, **27**, 5435 (1962); (b) R. N. McDonald and H. E. Petty, *ibid.*, **37**, 2957 (1972).
(5) (a) K. Hafner, H. Pelster, and H. Patzett. *Justus Liebigs Ann. Chem.*, **650**, 80 (1961); (b) M. Scholz, L. Vien, G. Fischer, B. Tschapke, and M. Muhlstadt, *Chem. Ber.*, **100**, 375 (1967).
(6) Sodium *N*-methylanilide[5] failed to abstract a proton from the methyl group of 5-methylazulene at <20° to yield its conjugate base.
(7) We had observed ring addition with sodium *N*-methylanilide and 6-methylazulene at temperatures above 30°.
(8) R. A. Olofson and C. M. Dougherty, *J. Amer. Chem. Soc.*, **95**, 584 (1973), recently compared a variety of lithium amides in several reactions.
(9) (a) E. Heilbronner in "Non-Benzenoid Aromatic Compounds," D. Ginsburg, Ed., Interscience, New York, N. Y., 1959; (b) K. Hafner and H. Kaiser, *Justus Liebigs Ann. Chem.*, **618**, 140 (1958); (c) K. Hafner, C. Bernhard, and R. Muller, *ibid.*, **650**, 35 (1961).
(10) (a) A. G. Anderson, D. J. Gale, R. N. McDonald, R. G. Anderson, and R. C. Rhodes, *J. Org. Chem.*, **29**, 1373 (1964); (b) W. H. Stafford, J. P. Ward, and D. H. Reid, *Chem. Ind. (London)*, 1258 (1955).
(11) T. Nozoe, K. Takase, and M. Tada, *Bull. Chem. Soc. Jap.*, **36**, 1006 (1963).
(12) T. Nozoe, K. Takase, and M. Tada, *Bull. Chem. Soc. Jap.*, **38**, 247 (1965).
(13) It was observed that from hexane solutions of this blue solid a white precipitate slowly formed when the solutions were stored in laboratory light at 25° or in a freezer (dark) at −20°.
(14) A trityl group in the 1 position of azulene [1-tritylazulene, λ_{max} (C_6H_6) 602 nm, and 1,3-ditritylazulene, λ_{max} (C_6H_6) 619 nm][15] causes a +20 nm change in λ_{max} from azulene. A 6-alkyl group has $\frac{2}{3}$ of the absolute magnitude of $\Delta\lambda_{max}$ as does a 1-alkyl group. Assuming that this ratio holds for the trityl groups we would predict **19** to have λ_{max} 570 nm. Considering the differences in solvent and crudeness of the comparison, the agreement is quite good.
(15) K. Hafner, A. Stephan, and C. Bernard, *Justus Liebigs Ann. Chem.*, **650**, 42 (1961).
(16) In the present context, the term azulenate will refer to the cross- or through-conjugated divinyl- or butadienylcyclopentadienyl anion structures, respectively, as in **20** (**22**) and **21** as suggested by Hafner.[9c]
(17) The chemical shifts of the azulenate anions reported are sensitive to changes in solvent and temperature.
(18) M. J. Perkins, *Chem. Commun.*, 231 (1971), reported that 5-chloroacenaphthylene is converted into 5-ethoxyacenaphthylene by reaction with ethoxide ion and proposed a substituted indenyl anion as the intermediate.
(19) K. Hafner and H. Welds, *Justus Liebigs Ann. Chem.*, **606**, 90 (1957).
(20) Reinvestigation of this overall result has shown it to be correct (ref 3).
(21) We thank Professor K. Hafner for this latter suggestion, which stems from his observations that carboxylated cyclopentadienes are more acidic than cyclopentadiene.
(22) Melting points were determined on a Kofler hot stage and are uncorrected. Spectra were determined with commercial instruments (ir, Perkin-Elmer 137; nmr, Varian T-60; visible–uv, Cary 11; mass, AEI MS-9). Nmr spectral data are listed as centers except for multiplets where the range of the signals is given. All alumina is F-20 Alcoa, basic alumina, activity I assumed, unless otherwise specified.
(23) A. G. Anderson, R. Scotoni, E. J. Cowles, and C. G. Fritz, *J. Org. Chem.*, **22**, 1193 (1957).
(24) Water (3%) added.
(25) T. Nozoe, S. Seto, and S. Matsumura, *Bull. Chem. Soc. Jap.*, **35**, 1990 (1962).
(26) W. Treibs, *Chem. Ber.*, **92**, 2152 (1959).