[CONTRIBUTION FROM THE CHEMICAL LABORATORY OF HARVARD UNIVERSITY]

Condensation of Thienylcycloalkenes with Maleic Anhydride[1]

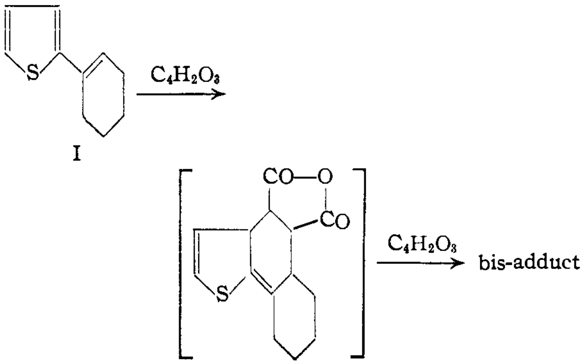
BY JACOB SZMUSZKOVICZ[2] AND EDWARD J. MODEST[3]

The aromatic character of thiophene is intermediate between that of benzene and furan.[4] In harmony with the greater degree of resonance stabilization, thiophene is less reactive than furan in the Diels–Alder reaction: it does not add maleic anhydride.[5]

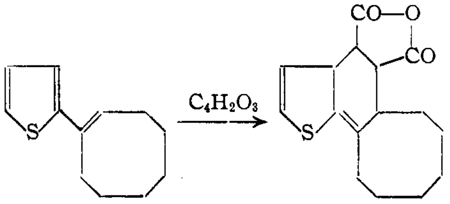
The addition of dienophiles to thiophene derivatives has been successfully accomplished only in the following instances. Clapp[6] condensed 2,3,4,5-di-(1′,8′-naphthylene)-thiophene with maleic anhydride at 225° and obtained 3,4,5,6-di-(1′,8′-naphthylene)-phthalic anhydride without isolating the addition product, which contains a sulfur bridge. Allen and Gates[7] effected the condensation of 1,3,5,6-tetraphenylisobenzothiophene with maleic anhydride and succeeded in isolating the sulfur-containing adduct, which they aromatized to a naphthalene derivative by heating in alcohol saturated with hydrogen chloride.

We have discovered that maleic anhydride adds readily to the diene system composed of one double bond of the thiophene nucleus and an alicyclic double bond, and we have carried out the addition with various 2-thienylcycloalkenes. In a typical case the adduct was isolated and then dehydrogenated to an aromatic anhydride. Subsequent decarboxylation led to a sulfur-containing hydrocarbon. In several cases the aromatic anhydrides were desulfurized to sulfur-free compounds.[8]

According to the analysis and neutralization equivalent, the adduct of 1-(2′-thienyl)-cyclohexene-1 (I) contains two molecules of the dienophile; also the tetracarboxylic acid derived from this bis-adduct has been prepared. Two other dienes, 1-(2′-thienyl)-4-methylcyclohexene-1 and 1-(2′-thienyl)-cycloheptene-1, yield bis-adducts. In view of the fact that bis-adducts are obtained from thienylcyclohexene and thienylcycloheptene, it is interesting that a mono-adduct, which we have represented as the primary addition product (III),[9] results from the addition of maleic anhydride to 1-(2′-thienyl)-cycloöctene-1 (II).



I



II III

The additions were carried out without solvent at steam-bath temperature except in cases 2, 3, 5 and 13, Table II. With the exception of the cases of bis-addition described above, those adducts isolated in crystalline form proved to be mono-adducts. When bis-addition occurs, the reaction mixture is yellow, crystals do not appear in less than an hour, and the melt does not solidify at steam-bath temperature; during mono-addition there is a red coloration, crystals appear within five minutes, and the melt turns completely solid. Furthermore the mono- and bis-adducts show striking differences in properties. The bis-adducts melt near 300°, form dense prismatic crystals, and can be crystallized repeatedly from polar solvents without apparent change. On the other hand the mono-adducts melt below 250°, form soft crystals, and are irreversibly affected by the action of polar solvents. If a mono-adduct is crystallized from a polar solvent and allowed to remain in contact with the mother liquor, the crystals that have deposited slowly redissolve and a red color is imparted to the solution. The original compound cannot be recovered from this red solution. If the mono-addition is carried out in ether or benzene, no red coloration is observed.

Crystallization of any of the mono-adducts, except III, is successful only if done very quickly. In the case of III the dissolution of crystals left in contact with the acetic acid mother liquor was also observed together with the appearance of a red color, but only after about two weeks. Evi-

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(4) Schomaker and Pauling, THIS JOURNAL, **61**, 1769 (1939).

(5) Diels, *Ber.*, **69A**, 195 (1936).

(6) Clapp, THIS JOURNAL, **61**, 2733 (1939).

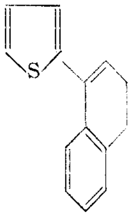
(7) Allen and Gates, *ibid.*, **65**, 1283 (1943).

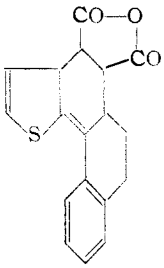
(8) Modest and Szmuszkovicz, *ibid.*, **72**, 577 (1950).

(9) In view of the high value of the absorption maximum of V, we wish to point out that the structures we have written for the mono-adducts represent only the initially formed products. In the future we plan to investigate the position of the double bonds in the addition products.

dently this compound is more stable than the other mono-adducts but less stable than the bis-adducts.

An explanation of this peculiar behavior in the presence of polar solvents has been suggested by an investigation of the ultraviolet absorption spectra[10] of 1-(2′-thienyl)-3,4-dihydronaphthalene (IV) and the corresponding mono-adduct (V).

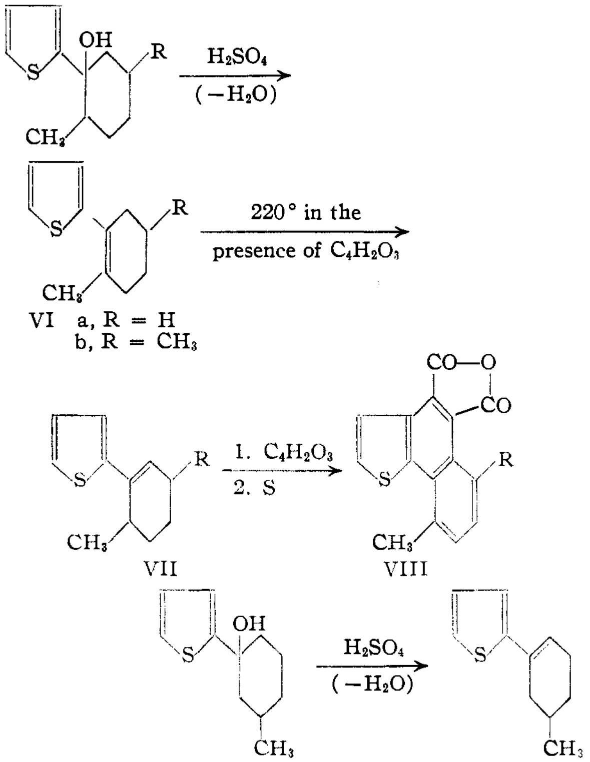

IV



V

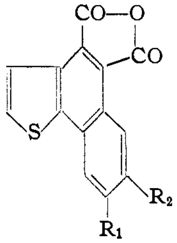
IV has an absorption maximum at 250 mμ (log ϵ 4.16). A freshly prepared ethanolic solution of V exhibits maxima at 237 mμ (log ϵ 3.97) and 317 mμ (log ϵ 3.97).[9] After a few days this solution shows only one maximum, at 250 mμ (log ϵ 4.15), and the absorption curve is nearly identical with that of IV. Therefore it is quite likely that the mono-adduct, in the presence of polar solvents, dissociates with regeneration of the diene.

In the preparation of 1-(2′-thienyl)-2-methylcyclohexene-1 (VIa), 1-(2′-thienyl)-2,5-dimethylcyclohexene-1 (VIb), and 1-(2′-thienyl)-5-methylcyclohexene-1 (IX), we assume that dehydration of the initially formed carbinols takes place as in the case of substituted 1-methylcyclohexanol-1.[11] In order to carry out the addition successfully with VIa and VIb, which contain ortho methyl substituents, we had to employ a reaction temperature of 220°. The crude hydroaromatic adducts obtained were dehydrogenated directly with sulfur. Since no methyl groups were lost during aromatization, we assume a prior shift of the double bond away from the ortho methyl group into the alternative position of conjugation with the thiophene ring (VIIa, VIIb).

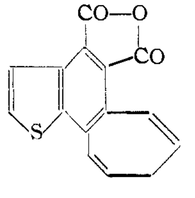


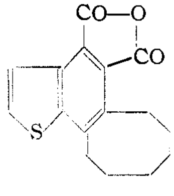
VI a, R = H
b, R = CH3
VII
VIII
IX

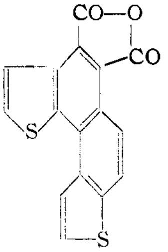
All the hydroaromatic adducts were dehydrogenated with sulfur in good yield to aromatic anhydrides (Table III). When V is treated with sulfur, two different products can be obtained according to the reaction temperature employed: a fully aromatic anhydride melting at 292° and a hydroaromatic product melting at 231°. We assume that selective aromatization of ring A, with formation of XVII, is achieved when the reaction temperature is carefully controlled, and that com-

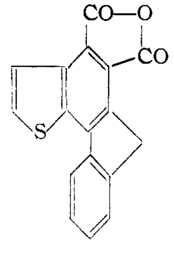


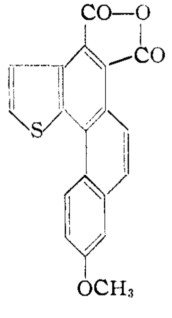
X a, $R_1 = R_2 = H$
b, $R_1 = CH_3$; $R_2 = H$
c, $R_2 = CH_3$; $R_1 = H$


XI

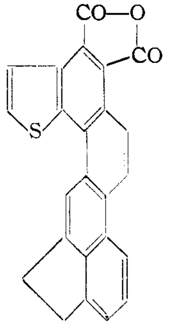

XII


XIII


XIV



XV


XVI

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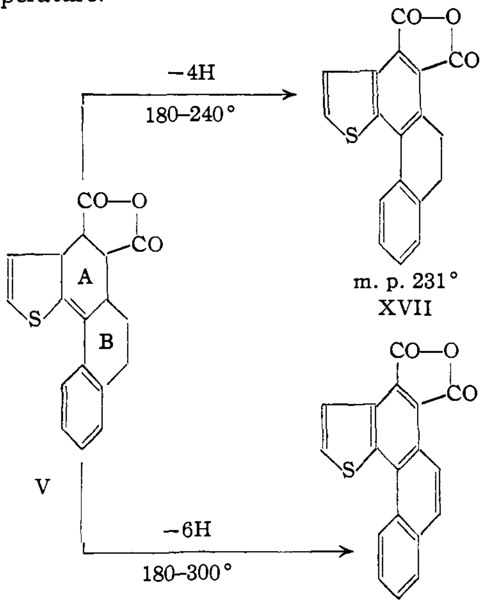
[10] The ultraviolet absorption spectra of IV and V in ethanol were measured with a Beckman model DU quartz spectrophotometer.

[11] Wallach, *Ann.*, **396**, 264 (1913).

plete dehydrogenation to XVIII ensues at higher temperature.

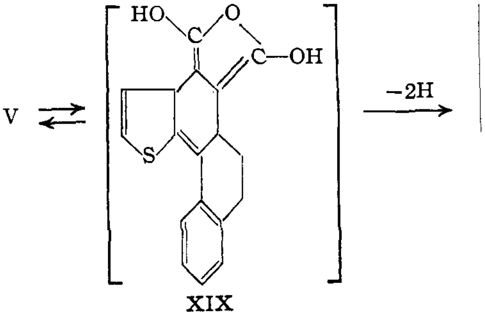


V

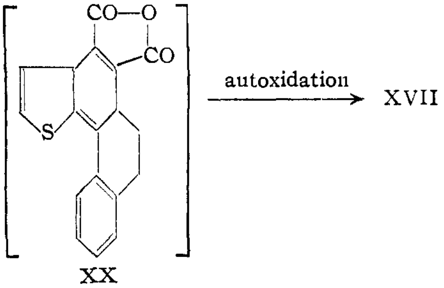
m. p. 231°
XVII

m. p. 292°
XVIII

Dehydrogenation of ring A prior to that of ring B is expected. The most labile hydrogen atoms in V are the two that are adjacent to the carbonyl groups. The partial dehydrogenation (compare refs. 12, 13) probably proceeds through the dienediol intermediate (XIX).

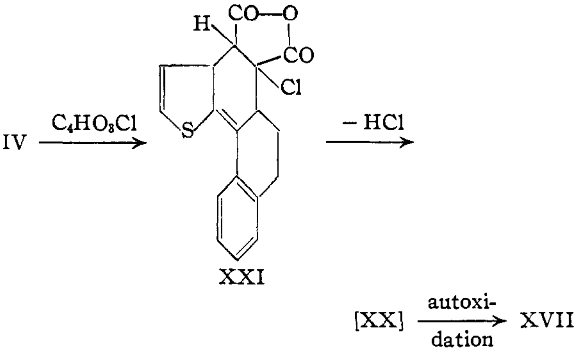


XIX



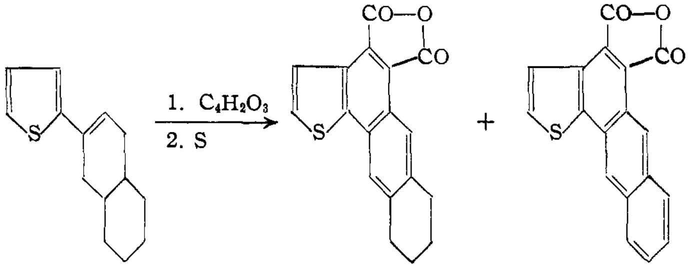
XX

We synthesized XVII by an independent method, in order to provide further evidence in favor of our assumption. IV reacts with chloromaleic anhydride and the adduct XXI is formed. During sublimation XXI loses a molecule of hydrogen chloride, and the unstable intermediate XX is autoxidized to XVII (compare refs. 14, 15).



XXI

A Grignard reaction between 2-bromothiophene and *trans*-decalone-2 afforded XXII. We propose structures for this compound and for XXIV on the basis of the fact that the closely related 2-phenyloctahydronaphthalene, after addition of maleic anhydride, dehydrogenation and decarboxylation, is transformed into 1,2-benzanthracene, not chrysene.[16]



XXII

m. p. 213°
XXIII

m. p. 234°
XXIV

In the sulfur dehydrogenation of the crude hydroaromatic adduct of XXII we again observed the phenomenon of partial aromatization. Fractional crystallization of the sublimed dehydrogenation product provided, in addition to the major product (XXIV), m. p. 234°, a small amount of XXIII, m. p. 213°, for which a possible structure is presented.

Two additions were carried out in the thianaphthylcycloalkene series. Direct bromination of thianaphthene affords 3-bromothianaphthene, which was used to prepare 1-(3′-thianaphthyl)-cyclohexene-1 (XXV) and 1-(3′-thianaphthyl)-3,4-dihydronaphthalene (XXVIII). Maleic anhydride adds to XXV and a mono-adduct (XXVI)[9] is formed which exhibits dimorphism. XXVI was aromatized to XXVII. The hydroaromatic adduct of XXVIII, which was not obtained in crystalline form, was dehydrogenated to XXIX.

Decarboxylation of the aromatic anhydrides (Xa), (XVIII) and (XV) by means of barium hy-

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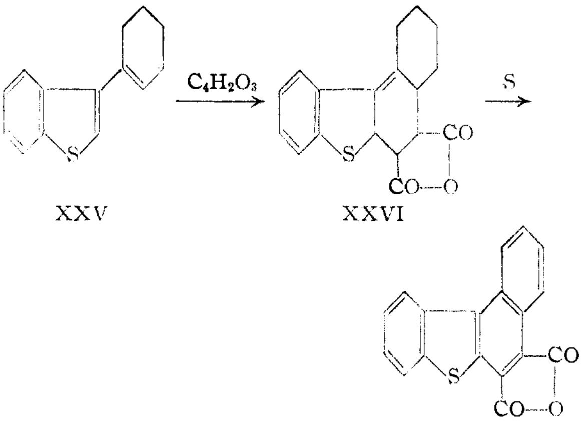
(12) F. Bergmann, THIS JOURNAL, **64**, 176 (1942).

(13) F. Bergmann and Szmuszkovicz, *ibid.*, **69**, 1777 (1947).

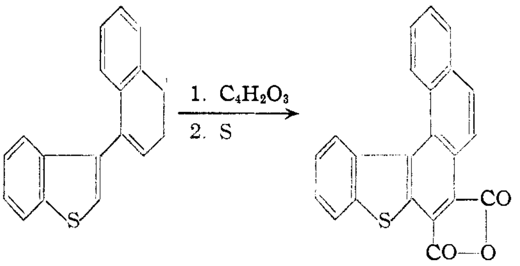
(14) Fieser and Dunn, *ibid.*, **59**, 1016, 1024 (1937).

(15) Synerholm, *ibid.*, **67**, 345, 1229 (1945).

(16) Szmuszkovicz and Modest, *ibid.*, **72**, 566 (1950).

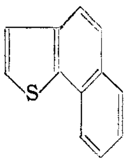


XXV XXVI XXVII

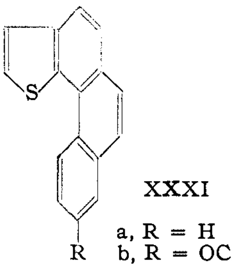


XXVIII XXIX

droxide and copper–bronze afforded thiopheno-2,3:1′,2′-naphthalene (XXX), thiopheno-2,3:3′,4′-phenanthrene (XXXIa) and thiopheno-2,3:3′,4′-(7′-methoxy)-phenanthrene (XXXIb), respectively.



XXX



XXXI

a, R = H
b, R = OCH_3

Some of these sulfur-containing hydrocarbons, especially the thiophene isologs of 3,4-benzphenanthrene, may prove to be carcinogenic.

We are planning to investigate further the structures of the mono- and bis-adducts and of the decarboxylated products.

Acknowledgment.—The authors wish to express their appreciation to Professor Louis F. Fieser for his kind interest and support during this investigation and to Mrs. Mary Fieser for her advice and assistance in preparing the manuscript. The microanalyses were performed by Mrs. Shirley R. Golden.

Experimental[17]

Preparation of Starting Materials (Table I).—All starting materials were prepared by means of the Grignard reaction, which was carried out in the following way. The reagent was formed from 16.3 g. (0.1 mole) of 2-bromothiophene and 2.5 g. of magnesium in 100 cc. of ether. Addition of the halide took fifteen minutes and was followed by a ten-minute reflux. The mixture was cooled in ice and 0.1 mole of the appropriate ketone in 100 cc. of benzene was added. The reaction mixture was then refluxed for three hours and left overnight. It was decomposed by 10% sulfuric acid and ice, extracted with ether, washed with dilute bisulfite solution and with water, and dried over anhydrous sodium sulfate. Distillation yielded the required thienylcycloalkene directly.

Tetralone-1.—We have prepared this ketone in 82.8% yield by cyclization of γ-phenylbutyric acid with stannic chloride, employing essentially the procedure of Thomas and Nathan for the synthesis of 7-methoxytetralone-1.[18]

3-Bromothianaphthene.—In a 2-l. three-necked flask provided with a mechanical stirrer, dropping funnel and drying tube was placed a mixture of 71.9 g. of thianaphthene, 73.0 g. of anhydrous sodium acetate and 380 cc. of chloroform. A solution of bromine (28 cc.) in 70 cc. of chloroform was added dropwise with stirring over a period of twenty-five minutes. The reaction required intermittent cooling. Stirring was continued for an hour and then 100 cc. of water was added to dissolve the inorganic material. The chloroform solution was separated from the aqueous layer, washed with 200 cc. of water, 100 cc. of 5% sodium hydroxide solution, 200 cc. of water and 200 cc. of saturated sodium chloride solution, and filtered slowly through anhydrous sodium sulfate. Distillation, after solvent removal, gave 83.8 g. (73.6%) of 3-bromothianaphthene,[19] a light yellow oil boiling at 90–105° (1.5 mm.). The best product distilled at 95° (1.5 mm.).

1-(3′-Thianaphthyl)-cyclohexene-1 (XXV).—The Grignard reagent was formed from 16 g. of 3-bromothianaphthene and 1.88 g. of magnesium. The reaction was induced with methyl iodide and iodine and at no time was vigorous. After a three-hour reflux a considerable amount of the magnesium turnings had not reacted. The solution was cooled and 8.11 g. of cyclohexanone in benzene solution was added. The mixture was refluxed for eighteen hours and decomposed with 10% sulfuric acid. The organic layer was washed as usual. XXV was obtained as a yellow oil (11.2 g., 69.5%) boiling at 120–140° (0.1 mm.). The analytical sample distilled at 135° (0.1 mm.).

Anal. Calcd. for $C_{14}H_{14}S$: C, 78.45; H, 6.58. Found: C, 78.18; H, 6.74.

1-(3′-Thianaphthyl)-3,4-dihydronaphthalene (XXVIII).—The Grignard synthesis was performed as in the preceding case with 16 g. of 3-bromothianaphthene, 1.88 g. of magnesium and 10.97 g. of tetralone-1. On distillation 9.2 g. (46.7%) of XXVIII was obtained, a very viscous yellow oil which soon becomes red.

Anal. Calcd. for $C_{18}H_{14}S$: C, 82.40; H, 5.38. Found: C, 82.48; H, 5.30.

The yields of the latter two Grignard reactions could undoubtedly be improved if the reactions were carried out with methyl iodide as an entrainer.

1-(2′-Thienyl)-naphthalene.—1-(2′-Thienyl)-3,4-dihydronaphthalene (IV) (1.06 g.) and sulfur (0.17 g.) were heated for twenty minutes at 220–240°. A trace of copper–bronze was added and 1-(2′-thienyl)-naphthalene was isolated by distillation, a yellow oil, b. p. 165° (1 mm.). An attempt to form the picrate failed.

Anal. Calcd. for $C_{14}H_{10}S$: C, 79.96; H, 4.79. Found: C, 79.74; H, 4.72.

Condensation with Maleic Anhydride (Table II).—The additions were carried out without solvent on the steam-bath for various lengths of time, except in cases 2, 3, 5 and 13. A ratio of 1 g. of diene to 2.5 g. of maleic anhydride was used. When the diene was added to the dienophile, the mixture immediately assumed a yellow color, which deepened upon the application of heat. With compounds 1, 4 and 6, the color remained deep yellow throughout the re-

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[17] All melting points are corrected.

[18] Thomas and Nathan, THIS JOURNAL, 70, 333 (1948).

[19] Compare Komppa, *J. prakt. Chem.*, 122, 319 (1929).

TABLE I

THIENYLCYCLOALKENES

No.	Thienyl cycloalkene	Yield, %	B. p., °C.	B. p., Mm.	Formula	Analyses, % Calcd. C	Calcd. H	Found C	Found H
1	1-(2'-Thienyl)-cyclohexene-1[a]								
2	1-(2'-Thienyl)-2-methylcyclohexene-1	73.0	101	3	$C_{11}H_{14}S$	74.09	7.91	74.10	7.89
3	1-(2'-Thienyl)-5-methylcyclohexene-1	92.5	90	0.5	$C_{11}H_{14}S$	74.09	7.91	73.99	8.09
4	1-(2'-Thienyl)-4-methylcyclohexene-1	99.2	104	0.4	$C_{11}H_{14}S$	74.09	7.91	74.35	7.92
5	1-(2'-Thienyl)-2,5-dimethylcyclohexene-1	36.5	95	1	$C_{12}H_{18}OS$[b] $C_{12}H_{16}S$[c]	68.52 74.94	6.85 8.39	72.71	7.46
6	1-(2'-Thienyl)-cycloheptene-1	67.6	106	0.05	$C_{11}H_{14}S$	74.09	7.91	73.93	7.93
7	1-(2'-Thienyl)-cycloöctene-1	59.3	127	3	$C_{12}H_{16}S$	74.94	8.39	75.01	8.26
8	4-(2'-Thienyl)-6,7-dihydrothianaphthene	70.0	127	0.05[d]	$C_{12}H_{10}S_2$	66.04	4.62	66.19	4.74
9	3-(2'-Thienyl)-indene	65.6	120	0.2	$C_{13}H_{10}S$	78.75	5.08	78.70	5.11
10	1-(2'-Thienyl)-3,4-dihydronaphthalene	71.8	149.5	3[e]	$C_{14}H_{12}S$	79.20	5.70	79.15	5.77
11	1-(2'-Thienyl)-6-methoxy-3,4-dihydronaphthalene	81.3	137	0.01	$C_{15}H_{14}OS$	74.35	5.82	73.96	6.20
12	1-(2'-Thienyl)-3,4-dihydroacephenanthrene	85.0	196	0.02[f]	$C_{20}H_{16}S$	83.29	5.59	83.50	5.16
13	2-(2'-Thienyl)-1,4,5,6,7,8,9,10-octahydronaphthalene	92.5	135	0.1[g]	$C_{14}H_{18}S$	77.01	8.31	76.70	8.51

[a] Fieser and Szmuszkovicz, THIS JOURNAL, **70**, 3352 (1948). [b] Formula for the carbinol. [c] Formula for the cyclohexene. [d] Hexagonal plates from methanol, which soon turn yellow and then brown; m. p. 32–33°. [e] Colorless prismatic columns from methanol, m. p. 80.8–81.1°. [f] Colorless rods from isopropanol, m. p. 103.2–104.6°. [g] Colorless prismatic rods from methanol, m. p. 53.0–55.0.

TABLE II[a]

THIENYLCYCLOALKENE ADDUCTS

Adduct of	React. time,[b] min.	M. p., °C.	Crystal form	Solvent for cryst.	Formula	Analyses, % Calcd. C	Calcd. H	Found C	Found H
1[c]	180	303–304.5	Prisms	HOAc–Ac_2O	$C_{18}H_{16}O_6S$[d]	59.99	4.48	60.05	4.73
2[e]									
3[e]									
4	900[f]	254–257	Prisms	HOAc–Ac_2O	$C_{19}H_{18}O_6S$[d]	60.95	4.85	60.73	4.74
5[e]									
6	60[f]	306–307	Prisms	HOAc–Ac_2O	$C_{19}H_{18}O_6S$[d]	60.95	4.85	60.77	4.92
7	15	132–145	Needles	HOAc	$C_{16}H_{18}O_3S$	66.18	6.24	66.33	6.19
8	1/2	179–180	Needles	HOAc[g]	$C_{16}H_{12}O_3S_2$	60.74	3.83	60.66	4.05
9	1/2	212–213	Needles	HOAc	$C_{17}H_{12}O_3S$	68.90	4.08	68.84	4.26
10	4	212.9–213.4	Plates	HOAc–Ac_2O	$C_{18}H_{14}O_3S$	69.66	4.66	69.59	4.78
11	1/2	207.6–210.1	Needles	HOAc	$C_{19}H_{16}O_4S$	67.05	4.71	66.64	4.64
12	1/2	240–241	Needles	Ac_2O[h]	$C_{24}H_{18}O_3S$	74.59	4.70	74.32	4.96
13[i]									

[a] All yields essentially quantitative. [b] Reactions carried out at steam-bath temperature unless otherwise noted. [c] The numbers refer to compounds in Table I. [d] Bis-adduct. [e] Adduct not isolated. Reaction conditions three hours at 220°. [f] Most of the product obtained in the form of the water-precipitated free acid. [g] The same product was obtained from a reaction conducted in refluxing ether for two hours. Sample for analysis taken directly from the reaction. *Anal.* Found: C, 60.68; H, 3.93. [h] The same product was obtained from a reaction conducted in refluxing benzene for two hours. Sample for analysis taken directly from the reaction. *Anal.* Found: C, 74.41; H, 4.52. [i] Adduct not isolated. Reaction conditions twenty-four hours at 120°.

action, and crystals of the adducts began to separate slowly from the melt in one hour or longer. With most of the other dienes (compounds 8-12), the color changed rapidly from deep yellow to deep orange and then red, and the reaction mixture became completely solid with crystals in less than five minutes. In the case of 1-(2'-thienyl)-cycloöctene-1 a red coloration was observed, and solidification occurred in about fifteen minutes. After the completion of the reaction the mixture was treated with warm acetic acid, cooled and filtered, and the crystals washed with acetic acid and cold methanol.

In cases 2, 3 and 5, the reaction was conducted at 220° for three hours, and in case 13 at 120° for twenty-four hours; the viscous brown mass obtained was cooled, dissolved in warm acetic acid and precipitated with water. These four crude adducts melt at about 100° and cannot be crystallized.

Tetracarboxylic Acid from the Bis-adduct of I.—Two hundred milligrams of the bis-adduct (compound 1, Table II) was heated on the steam-bath with 0.5 g. of sodium hydroxide in 2 cc. of water. A clear solution resulted in five minutes. Precipitation with hydrochloric acid gave a white solid, which crystallized from water in the form of clusters of rods, swelling at 160-170° and melting at 235-236°; very hygroscopic.

Anal. Calcd. for $C_{18}H_{20}O_8S$: C, 54.53; H, 5.20; neut. eq., 99.1. Found: C, 54.35; H, 5.19; neut. eq., 107.4.

Preparation of XXVI.—A mixture of 0.5 g. of XXV and 1.25 g. of maleic anhydride, heated on the steam-bath, deposited a mass of crystals in fifteen minutes. Acetic acid was added and the crystals were filtered, washed with acetic acid and methanol, and dried; 0.48 g. (66.0%), m. p. 200-240°. On quick crystallization from acetic

TABLE III

THIENYLCYCLOALKENE AROMATIC ADDUCTS

Aromatic anhydride	React. temp.,[a] °C.	Yield, %	M. p., °C.	Crystal form[b]	Solvent for cryst.	Formula	Analyses, % Calcd.		Found	
							C	H	C	H
Xa	270–290	50	251–252	Yell. need.	HOAc	$C_{14}H_6O_3S$	66.13	2.38	66.30	2.34
VIIIa	190–270	45	320[c]	Yell. need.	HOAc	$C_{15}H_8O_3S$	67.15	3.01	67.06	3.12
Xb	240–280	40	193–194	Yell. need.	HOAc	$C_{15}H_8O_3S$	67.15	3.01	66.88	3.01
Xc	245–295	70	219–220	Yell. need.	HOAc	$C_{15}H_8O_3S$	67.15	3.01	67.10	3.25
VIIIb	220–270	45	293–294[d]	Yell. need.	HOAc	$C_{16}H_{10}O_3S$	68.07	3.58	68.01	3.50
XI	140–290	35	255–256	Yell. need.	$CHCl_3$	$C_{15}H_8O_3S$	67.15	3.01	67.03	2.95
XII	205–280	40	164–165	Yell. prisms	HOAc	$C_{16}H_{14}O_3S$	67.11	4.93	66.77	4.94
XIII	180–310	85	301–302	Yell. need.	Ac_2O	$C_{16}H_6O_3S_2$	61.92	1.95	61.97	1.91
XIV	160–230	25	268–271[e]	Yell. need.	Ac_2O	$C_{17}H_8O_3S$	69.85	2.76	69.57	2.92
XVIII	180–300	100	291.5–292.5	Yell. need.	Ac_2O	$C_{18}H_8O_3S$	71.04	2.65	70.79	2.81
XV	165–300	100	263.4–263.9	Yell. need.	Ac_2O	$C_{19}H_{10}O_4S$	68.26	3.02	68.47	3.08
XVI	170–305	30	*ca.* 370	Orange need.	[f]	$C_{24}H_{12}O_3S$	75.77	3.18	75.76	2.97
XXIV	160–285	40	233–234	Crimson need.	Ac_2O	$C_{18}H_8O_3S$	71.04	2.65	70.98	2.66

[a] The reaction times vary from twenty to fifty minutes. [b] The aromatic anhydrides were purified by sublimation at 0.001 mm., then crystallization. [c] Starts shrinking at 270°; viscous mass at 310°; complete melt at 320°. [d] Starts shrinking at 240°. [e] Resolidifies immediately after melting. [f] This compound was crystallized from bromobenzene or tetrachloroethane. The analytical sample was purified by sublimation at 280° (0.001 mm.).

anhydride hexagonal plates melting at 215-218° were obtained. The analysis shows that this compound is a monoadduct.

Anal. Calcd. for $C_{18}H_{16}O_3S$: C, 69.21; H, 5.16. Found: C, 69.33; H, 5.26.

If the period of heating is prolonged, the initially formed crystals dissolve to some extent and a brown melt results. After the addition of acetic acid the quantity of crystalline adduct increased substantially. In this way 1.0 g. of the diene afforded 0.85 g. (58.3%) of adduct, m. p. 185-195°. Crystallization from acetic acid or acetic anhydride yielded a mixture of small plates and rods. This mixture melts at 199-200° and has the following analysis.

Anal. Calcd. for $C_{18}H_{16}O_3S$: C, 69.21; H, 5.16. Found: C, 69.07; H, 5.05.

If this mixture of crystals is extracted with an insufficient quantity of boiling acetic acid and the extract is filtered and cooled immediately, thin, needle-like rods can be isolated, melting to a semi-solid at 230° and becoming a clear melt at 249-251°.

Anal. Calcd. for $C_{18}H_{16}O_3S$: C, 69.21; H, 5.16. Found: C, 69.14; H, 5.21.

Fractional crystallization of the mixture of small plates and rods from acetic acid resulted in a series of fractions of mixed crystals, each of which slowly changed, on standing for over a week, into a homogeneous crop of small, well-formed prisms, which start to melt at 187° and melt completely at 200°. The solidified melt has a m. p. of 199-200°. This prismatic crystalline modification appears to be the dicarboxylic acid, which forms by reaction of the anhydride with the small amount of water in the solvent used for crystallization.

Anal. Calcd. for $C_{18}H_{18}O_4S$: C, 65.43; H, 5.49. Found: C, 65.24; H, 5.43.

Dehydrogenation (Table III).—Dehydrogenation of the hydroaromatic adducts was carried out with sulfur (10-50% excess of theoretical quantity). Purification of the crude aromatic anhydrides was achieved first by sublimation at 200-300° (0.001 mm.) and then by crystallization. Crystalline adducts were used for dehydrogenation wherever possible; otherwise aromatization was conducted with crude, water-precipitated adducts.

Partial Aromatization of V.—If the dehydrogenation of V is conducted between 180 and 240° for eighteen minutes, a substance (XVII) can be isolated by sublimation at 195-205° (0.005 mm.) and fractional crystallization of the sublimate from acetic anhydride; yellow prisms, m. p. 225-227°. Recrystallization from acetic acid afforded yellow hexagonal plates, m. p. 230-231°.

Anal. Calcd. for $C_{18}H_{10}O_3S$: C, 70.59; H, 3.29. Found: C, 70.60; H, 3.30.

Alternative Synthesis of XVII.—A mixture of 0.5 g. of IV and 3 g. of chloromaleic anhydride was heated on the steam-bath for ten hours. A red solution was obtained, which did not deposit crystals over a period of two days. Treatment with methanol produced a red precipitate (XXI), m. p. 150-160°, which could not be crystallized. It gave a positive Beilstein test for halogen. The analysis shows that some hydrogen chloride was lost.

Anal. Calcd. for $C_{18}H_{13}O_3SCl$: C, 62.70; H, 3.80. Found: C, 64.84; H, 4.01.

The red substance was heated at 220-280° (0.001 mm.) and a yellow sublimate melting at 227-229° was obtained. It crystallized from acetic acid in the form of yellow plates, m. p. 230-231°, and is identical with XVII (mixed m. p. determination).

Partial Dehydrogenation of the Adduct of XXII.—Dehydrogenation was carried out with the crude, water-precipitated adduct as outlined in the case of XXIV, Table III. By fractional crystallization of the crude sublimate from acetic acid, orange rods (XXIII), m. p. 212-213°, could be isolated, in addition to the completely aromatic product.

Anal. Calcd. for $C_{18}H_{12}O_3S$: C, 70.11; H, 3.92. Found: C, 70.38; H, 3.80.

Dehydrogenation of XXVI.—Four hundred milligrams of XXVI was ground with 246 mg. of sulfur and heated for twenty-eight minutes at 180-285°. Sublimation at 230-260° (0.02 mm.) gave a quantitative yield of yellow crystals (XXVII), m. p. 240-260°. Slender yellow rods crystallized from dioxane, m. p. 267.5-268.5° with prior shrinking.

Anal. Calcd. for $C_{18}H_8O_3S$: C, 71.04; H, 2.65. Found: C, 70.86; H, 2.80.

Preparation of XXIX.—Since in this case no crystalline addition product was obtained, the dehydrogenation was carried out with the crude, precipitated adduct. The diene (XXVIII) (1.25 g.) and maleic anhydride (2.5 g.) were heated for twenty-eight hours at steam-bath temperature. The reaction mixture was dissolved in acetic acid, and after the addition of water the crude adduct was collected and dried. Sulfur (685 mg.) was mixed with this material and dehydrogenation was conducted for thirty minutes at 225-315°. After sublimation at 320-370° (0.005 mm.), 0.5 g. (29.6%) of orange crystals (XXIX) was obtained, m. p. 250-280°. Crystallization from dioxane yielded long yellow needles, m. p. 296-297°.

Anal. Calcd. for $C_{22}H_{10}O_3S$: C, 74.56; H, 2.85. Found: C. 74.52; H, 3.01.

Decarboxylation.—As a general procedure a mixture of aromatic anhydride (0.5 g.), crystalline barium hydroxide (2 g.) and copper-bronze (0.7 g.) was ground thoroughly in an agate mortar and was heated in a long Pyrex tube. Water of crystallization was collected up to 220°. As soon as the reaction started (about 300°), one end of the tube was fitted with a capillary and the other end was connected to water-pump suction. Heating was continued at 300–350° under reduced pressure till no more oil was evolved.

Thiopheno-2,3:1′,2′-naphthalene (XXX).—Decarboxylation of 0.5 g. of Xa gave 0.2 g. (55.5%) of an oil, which was treated with picric acid in ethanol; crude picrate, m. p. 135°. After crystallization from a saturated solution of picric acid in ethanol, orange needles were obtained, m. p. 141–142°.

Anal. Calcd. for $C_{18}H_{11}O_7N_3S$: C, 52.30; H, 2.68. Found: C, 52.32; H, 2.51.

The picrate was decomposed with dilute alkali, and a yellow oil (XXX) was formed.

Anal. Calcd. for $C_{12}H_8S$: C, 78.22; H, 4.38. Found: C, 78.15; H, 4.47.

Thiopheno-2,3:3′,4′-phenanthrene (XXXIa).—On decarboxylation of 0.5 g. of XVIII there resulted 192 mg. (50%) of an oil which solidified immediately, m. p. 70–75°. Two crystallizations from dilute ethanol afforded colorless, branched leaflets melting at 91.5–92.5°.

Anal. Calcd. for $C_{16}H_{10}S$: C, 82.01; H, 4.30. Found: C, 81.93; H, 4.23.

The picrate was formed in methanol and was crystallized from the same solvent as elongated orange needles, m. p. 170–171°.

Anal. Calcd. for $C_{22}H_{13}O_7N_3S$: C, 57.02; H, 2.82. Found: C, 57.47; H, 2.47.

Thiopheno-2,3:3′,4′-(7′-methoxy)-phenanthrene (XXXIb).—XV was decarboxylated to an oil which solidified; yield 44.3%. The picrate was formed in ethanol and was crystallized from a dilute solution of picric acid in ethanol as brick-red needles, m. p. 138–138.5°.

Anal. Calcd. for $C_{23}H_{15}O_8N_3S$: C, 55.99; H, 3.06. Found: C, 56.29; H, 2.93.

Decomposition of the picrate yielded a white solid, which crystallized from methanol in the form of needles melting at 88.5–90.0°.

Anal. Calcd. for $C_{17}H_{12}OS$: C, 77.24; H, 4.58. Found: C, 77.09; H, 4.30.

Thiopheno-2,3:1′,2′-anthracene.—Decarboxylation of XXIV afforded a red oil which solidified. This red solid was heated overnight in refluxing ethanol. The solution was clarified by filtration and used directly for picrate formation. The red picrate which formed was crystallized from methanol; dark red rods, m. p. 139–140°.

Anal. Calcd. for $C_{22}H_{13}O_7N_3S$: C, 57.02; H, 2.82. Found: C, 57.17; H, 2.37.

Preliminary efforts to isolate the sulfur-containing hydrocarbon by the general method, as well as by decarboxylation with quinoline and copper-bronze, were unsuccessful.

Summary

1. Conjugation of one double bond of the thiophene nucleus and an alicyclic double bond has been found to provide an active diene system for the Diels–Alder reaction with maleic anhydride.

2. The condensation with maleic anhydride has been effected with a number of 2-thienyl- and 3-thianaphthylcycloalkenes. The hydroaromatic adducts were dehydrogenated to aromatic anhydrides.

3. Decarboxylation of several aromatic anhydrides has afforded sulfur-containing hydrocarbons, which may prove to be carcinogenic.

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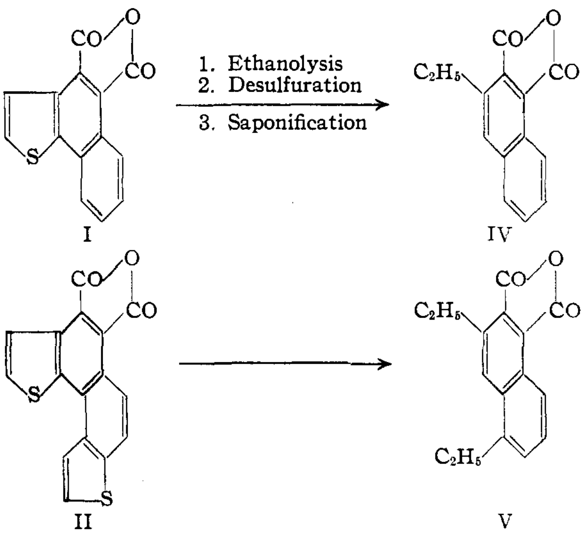
[CONTRIBUTION FROM THE CHEMICAL LABORATORY OF HARVARD UNIVERSITY]

Preparation of Substituted Aromatic Anhydrides by Reductive Desulfuration

BY EDWARD J. MODEST[1] AND JACOB SZMUSZKOVICZ[2]

The desulfuration reaction with Raney nickel has already been applied to certain derivatives of thiophene. Bougault and co-workers[3] have reported a method for the removal of undesired thiophene derivatives from aromatic hydrocarbons by means of Raney nickel; and du Vigneaud and associates,[4] in their work on the elucidation of the structure of biotin, desulfurized a tetrahydrothiophene ring. In a recent article Blicke and Sheets[5] describe the desulfuration of thianaphthenecarboxylic acids.

Reductive desulfuration of the sulfur-containing aromatic anhydrides I, II, IIIa and IIIb[6] afforded naphthalene and phenanthrene derivatives. During treatment with Raney nickel the thiophene nucleus is cleaved and converted into an ethyl group with loss of sulfur.



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[3] Bougault, Cattelain and Chabrier, *Bull. soc. chim.*, [5] **7**, 780 (1940).

[4] du Vigneaud, *et al.*, *J. Biol. Chem.*, **146**, 475 (1942).

[5] Blicke and Sheets, THIS JOURNAL, **70**, 3768 (1948). Our investigation was completed before publication of this article.

[6] Szmuszkovicz and Modest, *ibid.*, **72**, 571 (1950).