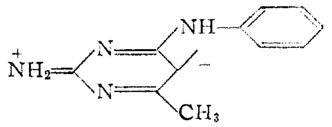
mono- and polynitrobenzene derivatives, pyridine and quinoline, pyrimidine activates alkyls and halogens in the 2-, 4- and 6-positions for condensation and replacement reactions, respectively.

The preferential substitution on the pyrimidine ring of 2-amino-4-anilino-6-methylpyrimidine (III) can be considered to result from the cumulative activation of the 5-position by electron release from the two amino and the methyl substituents. While the anilino nitrogen tends to activate the 4-position of the benzene ring, it can also activate the 5-position of the pyrimidine. In addition, the 2-amino and the 6-methyl of the pyrimidine should activate strongly the 5-position of the pyrimidine nucleus for attack by electrophilic reagents. The resonance variant shown (IIIA) is only one of those favoring substitution in the 5-position of this pyrimidine.



IIIA

That the combined influence of powerful activators, such as amino, is responsible for favored pyrimidine substitution is borne out by the more nearly equal distribution of substitution between the two rings when the simple amino is replaced by a second methyl group. In these cases the addition of one mole of bromine produces either a mixture of the products of mono-bromination on the pyrimidine or on the benzene nucleus, or gives the 5,4′-dibromo product directly.

Experimental

Intermediates.—Most of the intermediates used are known and references to them are given as they are mentioned in the text.

Preparations of Bromoanilinopyrimidines.—Two general methods were used for the preparation of the various bromoanilinopyrimidines: (A) direct bromination of anilinopyrimidines, and (B) interaction of an aniline (or a bromoaniline) with a chlorobromopyrimidine (or a chloropyrimidine) by a method similar to that of Banks.[1] Details for the individual reactions are summarized in Table I. An illustrative example of each method is described below.

(A) **Bromination of Anilinopyrimidines.**—To a suspension of 0.01 mole of the anilinopyrimidine in 25 cc. of glacial acetic acid, containing also 0.03 mole of anhydrous sodium acetate, was added dropwise with good mixing a solution of 0.01 mole of bromine in 10 cc. of glacial acetic acid. Bromine color usually disappeared instantly following each addition. When all the bromine had been added the reaction mixture was heated for one hour on a steam-bath. After cooling and diluting with 200 cc. of water, concentrated ammonium hydroxide was added to *p*H 9. The white crystalline precipitate was collected by filtration and was purified by recrystallization from aqueous alcohol or various other solvent combinations.

(B) **Interaction of an Aniline and a Chlorobromopyrimidine.**—A mixture of 0.01 mole of the chlorobromopyrimidine, 0.01 mole of aniline and 0.01 mole of concentrated hydrochloric acid in 30 cc. of water was heated for two hours at 100°. The reaction solution was then diluted with 100 cc. of water and concentrated ammonia added to *p*H 9. After cooling, the white crystalline product was collected and purified by recrystallization from appropriate solvents.

Acknowledgment.—The authors are indebted to S. W. Blackman and N. Martinez, Jr., for the microanalyses and to Miss Phoebe Lee Graham for some ultraviolet absorption spectra.

TUCKAHOE 7, NEW YORK

[CONTRIBUTION FROM THE MORLEY CHEMICAL LABORATORY OF WESTERN RESERVE UNIVERSITY]

Reactions of Terminally Substituted 1,3-Butadienes with Sulfur Dioxide

BY OLIVER GRUMMITT AND JANET SPLITTER[1]

RECEIVED SEPTEMBER 17, 1951

To determine the cause for the failure of *trans*-1-phenyl-1,3-butadiene to react with sulfur dioxide to give either a cyclic sulfone or a polysulfone, the behavior of the *trans*-isomers of 1-cyclohexyl-, 1-(*p*-nitrophenyl)- and 1-(*p*-anisyl)-1,3-butadiene with sulfur dioxide has been investigated. *trans*-1-Cyclohexyl-1,3-butadiene was made in 40% yield by the thermal decomposition of 1-cyclohexyl-3-acetoxy-1-butene. The isomeric 1-cyclohexylidene-2-butene was also obtained. The cyclohexylbutadiene added sulfur dioxide under the usual conditions to give both a cyclic and polymeric sulfone, thus pointing to the inductive and/or resonance effects of the phenyl group in phenylbutadiene as the critical factors. *p*-Nitrophenylbutadiene formed a cyclic sulfone, not a polysulfone, while *p*-anisylbutadiene formed neither. These results can be explained in terms of a polar mechanism of addition to a *cis*-butadienoid configuration which is energetically difficult if the 2,3-position in the side chain has a high degree of double bond character through resonance effects of the aryl group.

In earlier work on *cis*- and *trans*-1-phenyl-1,3-butadiene[2] the addition reaction with sulfur dioxide to form a cyclic sulfone (a dihydrothiophene-1-dioxide) was tried as a means of identifying and separating the isomers, as had been done successfully with the geometric isomers of piperylene.[3] The phenylbutadienes however did not react with sulfur dioxide, either through addition to form a cyclic sulfone or through copolymerization to a polysulfone. This study was made to explore the causes for this lack of reactivity.

Selected for investigation of their reactions with sulfur dioxide were the related dienes, *trans*-1-cyclohexyl-1,3-butadiene, *trans*-1-(*p*-nitrophenyl)-1,3-butadiene and *trans*-1-(*p*-anisyl)-1,3-butadiene. The behavior of the cyclohexyl compound would show the effect of a relatively large terminal group of non-aromatic character, located in the *trans* position. Only in the case of the piperylenes has the influence of a non-aromatic terminal group (methyl) on the reactivity with sulfur dioxide been determined: the *trans* isomer forms a sulfone readily, the *cis* reacts slowly and with initial

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(1) (a) Taken from Janet Splitter's Ph.D. thesis, Western Reserve University, June, 1950. (b) Presented before the Organic Division, A.C.S. Meeting, Chicago, Ill., Sept. 5, 1950.

(2) O. Grummitt and F. J. Christoph, THIS JOURNAL, **73**, 3479 (1951).

(3) D. Craig, *ibid.*, **65**, 1006 (1943).

isomerization to the *trans*.[3,4] Conceivably a larger terminal group might affect reactivity.[5]

The *p*-nitrophenyl and *p*-anisyl compounds allow changes in the inductive and resonance effects exerted by the phenyl group on the butadiene side chain to be observed. The nitro and methoxyl are similar in the direction of their inductive effect (+I) but opposite in their resonance effects; nitro withdraws electrons and methoxyl releases electrons to the ring.

Although 1-cyclohexyl-1,3-butadiene is mentioned by Alder, its preparation and properties are not given.[6] The first attempt used an acid-catalyzed dehydration of 1-cyclohexyl-2-buten-1-ol (I) in the hope that the normal product, 1-cyclohexylidene-2-butene (II) would rearrange to 1-cyclohexyl-1,3-butadiene (IV) or that the alcohol I would first rearrange to 1-cyclohexyl-1-buten-3-ol (III), a new compound, which would then dehydrate to IV. This reaction produced a mixture of dienes containing only about 20% of IV. Although it was found later that this mixture is separable, a better synthesis starts with the alcohol (III), made by reduction of 1-cyclohexyl-1-buten-3-one (V) with lithium aluminum hydride. This ketone was obtained by an aldol condensation of cyclohexanecarboxaldehyde (VII) and acetone.[7] The acid-catalyzed dehydration of III also gave a mixture of dienes II and IV which contained only about 30% of IV. Apparently the allylic rearrangement of the alcohols and/or dienes favors the formation of the isomer with the exocyclic double bond. Thermal decomposition of the acetate ester (VI) at 475° gave IV in 40% yield, thus demonstrating again that the ester → olefin route is accompanied by less rearrangement than dehydration of the corresponding alcohol.[8a,b]

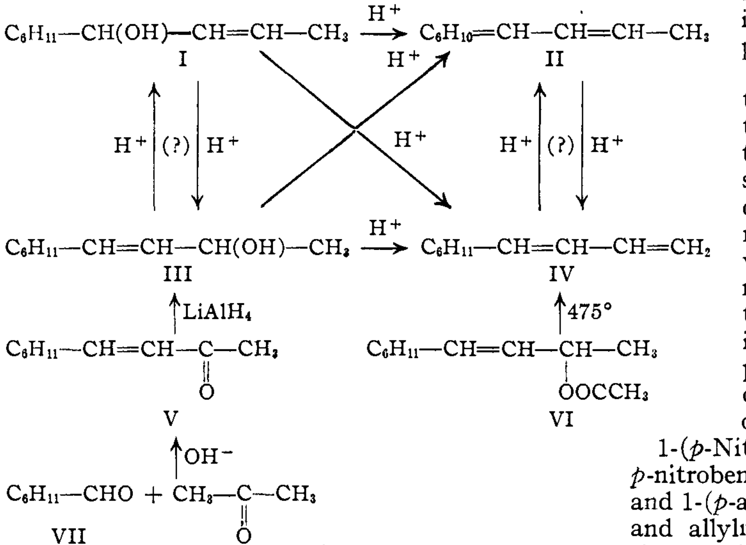

CHART I

On the basis of its reaction with 96% of the theoretical amount of maleic anhydride at room temperature in a Diels–Alder reaction,[2] the *trans* configuration was assigned to this 1-cyclohexyl-1,3-butadiene. The physical properties of a highly purified sample were: distillation temperature, 47° at 3.8 mm.; n^{20}_D 1.4925; d^{20}_4 0.8346. The ultraviolet and infrared spectra are shown in Figs. 1 and 2.[9] The maleic anhydride adduct melted 143–143.5° and by degradation to diphenyl its structure was indicated to be the expected 3-cyclohexyl-1,2,3,6-tetrahydrophthalic anhydride. The diene IV gave a solid tetrabromide melting 93–93.5°. With sulfur dioxide under the usual reaction conditions both a cyclic sulfone (m.p. 50–51°) and a polysulfone were obtained. The cyclic sulfone thermally dissociated at about 100° to the hydrocarbon and sulfur dioxide.[10] Therefore the failure of *trans*-phenyl-1,3-butadiene to react with sulfur dioxide is most probably due to inductive and/or resonance effects of the phenyl group.

The isomeric 1-cyclohexylidene-2-butene (II) obtained by fractional distillation of the higher boiling products from the acetate decomposition differed considerably in physical properties from IV: distillation temperature, 59–60° at 4 mm.; n^{20}_D 1.5105, d^{20}_4 0.8554, and ultraviolet absorption spectrum, Fig. 1.[11] It reacted with maleic anhydride at room temperature to only 10% of the theoretical extent and at 110° a resinous copolymer was produced. There was no cyclic sulfone formation with sulfur dioxide.

1-(*p*-Nitrophenyl)-1,3-butadiene was made from *p*-nitrobenzenediazonium chloride and butadiene[12] and 1-(*p*-anisyl)-1,3-butadiene from *p*-anisaldehyde and allylmagnesium chloride.[13,14] The quantitative reaction with maleic anhydride at room temperature[2] showed that the nitro compound consisted

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[4] The isomers show a similar difference in reactivity in the Diels–Alder reaction with maleic anhydride; R. Robey, C. Morrell and H. Wiese, *ibid.*, **63**, 627 (1941).

[5] The exact model compound here would be the hypothetical butadiene with a non-aromatic, hydrocarbon terminal radical identical in size and shape with the phenyl group. Admittedly the cyclohexyl group falls short of this in that it is larger and multiplanar instead of flat. Molecular volumes at 20°A. are 82.6 cc. for cyclohexane and 69.3 cc. for benzene; W. Heuse, *Z. physik. Chem.*, **A147**, 266 (1930). Nevertheless the cyclohexyl compound is the closest available approximation to the ideal model.

[6] K. Alder, "Newer Methods of Preparative Organic Chemistry," Interscience Publishing Co., New York, N. Y., 1948, p. 381.

[7] G. A. R. Kon, *J. Chem. Soc.*, 1792 (1926).

[8] (a) A. J. van Pelt and J. P. Wibaut, *Rec. trav. chim.*, **60**, 55 (1941); (b) C. S. Marvel and J. L. R. Williams, THIS JOURNAL, **70**, 3842 (1948).

[9] A comparison and discussion of the infrared spectra of this compound, the *cis*- and *trans*-piperylenes (R. S. Rasmussen and R. R. Brattain, *J. Chem. Phys.*, **15**, 131 (1947)), and the *cis*- and *trans*-1-phenyl-1,3-butadienes are given in ref. (1b).

[10] The physical properties of the regenerated hydrocarbon were almost identical with the original diene. Thus the formation and dissociation of the sulfone did not alter the configuration of the diene.

[11] These properties correspond approximately with those of the dehydration products of 1-cyclohexyl-2-buten-1-ol (I). Other structures for this product were considered, including that of *cis*-1-cyclohexyl-1,3-butadiene. The evidence, especially the spectroscopic data, favors 1-cyclohexylidene-2-butene (II); see ref. (1b). The action of ultraviolet light on these isomers would be interesting. The *trans*-1-cyclohexyl-1,3-butadiene might isomerize to the *cis* form, as does *trans*-1-phenyl-1,3-butadiene,[3] or to the cyclohexylidene isomer (II).

[12] E. C. Coyner and G. A. Ropp, THIS JOURNAL, **70**, 2283 (1948).

[13] R. T. Arnold and E. C. Coyner, *ibid.*, **66**, 1542 (1944).

[14] E. A. Braude, E. R. H. Jones and E. S. Stern, *J. Chem. Soc.*, 1087 (1947).

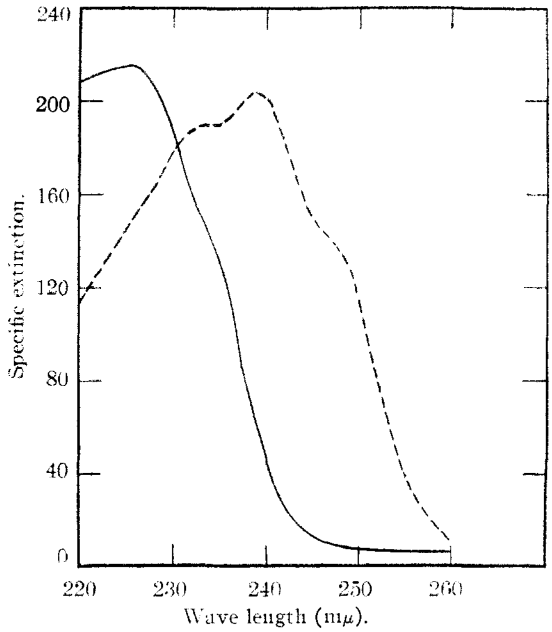


Fig. 1.—Ultraviolet absorption spectra of *trans*-1-cyclohexyl-1,3-butadiene (solid line), max. at 225 mμ, sp. extinction 216; and 1-cyclohexylidene-2-butene after sulfur dioxide treatment (broken line), max. at 238 mμ, sp. extinction 204. Determined on isoöctane solutions by a Beckman model DU quartz spectrophotometer.

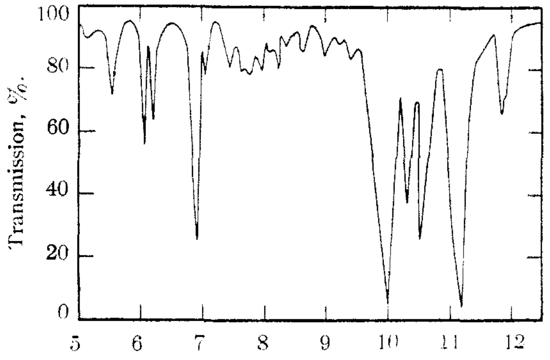
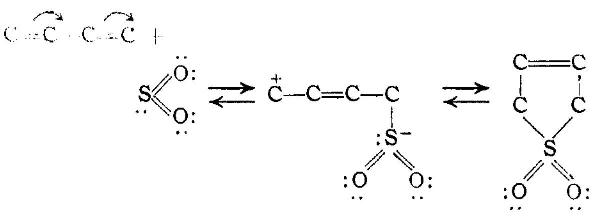


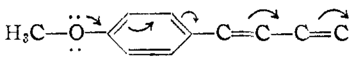
Fig. 2.—Infrared absorption spectrum of *trans*-1-cyclohexyl-1,3-butadiene. Determined with a Beckman model IR-2 spectrophotometer in which the cell thickness was 0.03 mm. A rock salt blank was used.

of 86% of the *trans* form and the anisyl compound was 90% *trans*. In reaction with sulfur dioxide the *p*-nitrophenylbutadiene gave a 41% yield of sulfone (m.p. 125–125.5°) at room temperature, only traces at 75–80°, but it did not copolymerize to a polysulfone. Since the mechanism of the copolymerization is probably free radical, the aromatic nitro grouping may have exerted its characteristic inhibition of the initiation step. *p*-Anisylbutadiene did not react with sulfur dioxide under any conditions.

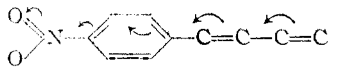
A polar mechanism for the 1,4-addition of sulfur dioxide to a conjugated diene analogous to the Diels–Alder reaction with maleic anhydride has been proposed[15]:



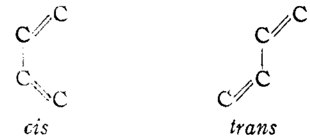
In electrophilic addition reactions to 1-phenyl-1,3-butadiene, as with hypochlorous acid for example,[16] the terminal carbon atom becomes strongly anionoid. Thus one would predict that phenylbutadiene should readily add sulfur dioxide and that the 1-(*p*-anisyl)-1,3-butadiene should be more reactive because of the electron release character of the methoxyl group



and the 1-(*p*-nitrophenyl)-1,3-butadiene should be least reactive because the resonance effect of the nitro group opposes this electron displacement into the side chain.



Since the experimental findings directly contradict these predictions, some other dominant factor is involved. Tentatively, it is suggested that the 1,4-addition of sulfur dioxide, like the addition of various dienophiles, requires a *cis*-butadienoid configuration in the diene[17]



and that the double bond character acquired by the 2,3-linkage of the butadiene side chain in the case of the phenyl and anisyl dienes reduces free rotation in the transition state to a degree that prevents addition.[18] The resonance effect of the nitro group offsets at least partially this condition, the *cis*-butadienoid arrangement is energetically possible, and addition takes place.[19] The fact that all of these dienes react with maleic anhydride indicates a greater driving force for the Diels–Alder process than for the cyclic sulfone formation. This may be due to the greater stability of a 6-membered ring over a 5-membered. It is interesting to note that, while *trans,trans*-1,4-diphenyl-1,3-butadiene

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[15] O. Grummitt, A. Ardis and J. Fick, This Journal, **72**, 5167 (1950).

[16] O. Grummitt and R. M. Vance, *ibid.*, **72**, 2669 (1950).

[17] J. A. Norton, *Chem. Revs.*, **31**, 319 (1942).

[18] The failure of certain 2,3-substituted butadienes to react with maleic anhydride has been attributed to this condition arising from steric hindrance or steric repulsion of the substituents. 2,3-Di-*t*-butyl-1,3-butadiene (H. J. Backer, *Rec. trav. chim.*, **58**, 643 (1939), and K. Alder, ref. 6, p. 382) and 2,3-dichloro-1,3-butadiene (G. J. Berchet and W. H. Carothers, THIS JOURNAL, **55**, 2004 (1933)) are examples.

[19] This explanation of the behavior of phenylbutadiene is applicable to other terminally substituted butadienes where the group exerts similar resonance effects. For example, 1-cyano- and 1-acetoxy-1,3-butadiene do not form cyclic sulfones but do react with maleic anhydride (Publication Board Rept. No. 73887, frames 7064–7069, Office of Technical Services, Department of Commerce, Washington, D. C.). A compilation of a number of substituted butadienes and their reactions with both sulfur dioxide and maleic anhydride is given in ref. (1a).

adds maleic anhydride,[20] *trans,trans*-1,4-di-(*p*-anisyl)-1,3-butadiene, in which the 2,3-position would have a very high double bond character, does not.[21]

Experimental

Dehydration of 1-Cyclohexyl-2-buten-1-ol (I).—The first experiments were patterned after the preparation of 1-phenyl-1,3-butadiene from cinnamaldehyde and methylmagnesium bromide.[22] To the Grignard reagent from 154 g. (0.94 mole) of cyclohexyl bromide and 24 g. (1.0 atom) of magnesium and 300 ml. of anhydrous ether was added a solution of 52.5 g. (0.75 mole) of crotonaldehyde in 100 ml. of ether over a period of 2 hours at 10–15°. Hydrolysis in 30% sulfuric acid gave 90 g. of crude product. The ether solution of the product stood for 4 days before distilling: (1) 10.4 g., $n^{26.6}_{\mathrm{D}}$ 1.4865, to 102° (22 mm.); (2) 26.1 g., $n^{26.6}_{\mathrm{D}}$ 1.4860, at 102–107° (15 mm.); (3) 41 g. of viscous residue. Redistillation of combined (1) and (2) gave: (1a) 13.0 g., n^{25}_{D} 1.4922, at 70–98° (14 mm.); (2a) 15.2 g., n^{25}_{D} 1.4864, at 94–115° (12 mm.). Fraction (1a), 13% yield, was negative in a Zerewitinoff test; the ultraviolet spectrum indicated the presence of conjugated dienes. Fraction (2a), 13% yield, was impure I. Hess and Wustrow[23] give a boiling point of 98–100° (13 mm.) and n^{16}_{D} 1.4799. On standing this alcohol became cloudy due to water and distillation yielded additional diene.

When fraction (1a) reacted with maleic anhydride[24] and the adduct was crystallized from acetic acid, the m.p. was 139–141°. Degradation in the presence of palladium[25] gave diphenyl, indicating that the adduct was 3-cyclohexyl-1,2,3,6-tetrahydrophthalic anhydride derived from 1-cyclohexyl-1,3-butadiene (*v.i.*). A mixture of 0.2 g. of adduct, 0.1 g. of 10% palladium-on-carbon and 1.2 ml. of thiophene-free benzene was shaken under nitrogen in a 110 ml. high pressure Aminco hydrogenation bomb at 300° for 7 hours. Washing out with Skellysolve C, filtering, evaporating the filtrate to dryness, and extracting the residue with 95% alcohol gave a soluble solid which melted 65–69°. After sublimation the m.p. was 68–69°; mixed m.p. with an authentic sample of diphenyl was 68–70°.

A second preparation of I in which the ether solution was distilled immediately instead of standing 4 days gave a 61% yield of product which was mainly alcohol. On standing this spontaneously dehydrated and diene could be separated by distillation.

In a third preparation the Grignard adduct was hydrolyzed with 120 ml. of saturated ammonium chloride solution, the crude yield of 79 g. was distilled: (1) 5.4 g., n^{25}_{D} 1.4750, at 60–70° (0.4 mm.); (2) 39.3 g., n^{25}_{D} 1.4775, at 67–68° (0.4 mm.); (3) 16.4 g., n^{25}_{D} 1.4782, at 68° (0.4 mm.); (4) 14 g. of residue. The first three fractions represent an alcohol yield of 53%. The absence of diene and the greater stability of the alcohol on standing indicated the dehydrating influence of the sulfuric acid hydrolysis and the possible presence of traces of acid or acid derivatives in the product of the first two runs.

The *p*-nitrobenzoate of 1-cyclohexyl-2-buten-1-ol (third run) prepared in the usual way[26] and crystallized from 95% ethanol melted 73.8–74.3°.

Anal. Calcd. for $C_{17}H_{21}NO_4$: C, 67.4; H, 6.93; N, 4.62. Found: C, 67.70; H, 7.19; N, 4.57.

The 3,5-dinitrobenzoate derivative[26] from 95% ethanol melted 101–101.5°.

Anal. Calcd. for $C_{17}H_{20}N_2O_6$: N, 8.04. Found: N, 7.97.

Dehydration of I with potassium acid sulfate was done by distilling a mixture of 8 g. of alcohol and 0.8 g. of catalyst under nitrogen at 0.5 mm. The distillate of 4.5 g. was redistilled: 1.3 g. (19%), b.p. 43–47° (0.5 mm.), n^{25}_{D} 1.5046. With maleic anhydride in benzene the adduct of 1-cyclohexyl-1,3-butadiene formed, m.p. 135–139°; this was not depressed in a mixed m.p. with the product obtained above. From the value of n^{25}_{D} 1.5046 and the indexes of the pure 1-cyclohexyl-1,3-butadiene and 1-cyclohexylidene-2-butene obtained later, it was estimated that 20% of cyclohexylbutadiene was present.

In a second dehydration the vapor of I was passed over activated alumina at 400–450°. A catalyst tube 18 mm. in diameter and 75 cm. long packed with 8–14 mesh alumina (Alorco Grade F-1) was heated electrically at 400–450° while 16 g. of alcohol was distilled through under nitrogen at 1.5 mm. in the course of one-half hour. The crude product of 9.5 g. was redistilled: 4.5 g. (32%), b.p. 45–60° (1.5 mm.), n^{26}_{D} 1.4829. This did not yield a crystalline adduct with maleic anhydride.

4-Cyclohexyl-3-buten-2-ol (III).—Three procedures for the preparation of cyclohexanecarboxaldehyde (VII) were tried. In the first[7] there was added to the Grignard reagent from 82 ml. (0.67 mole) of cyclohexyl bromide and 16 g. (0.67 atom) of magnesium and 280 ml. of anhydrous ether in the usual 3-necked flask apparatus 90 ml. (0.55 mole) of ethyl orthoformate (b.p. 142–145°) over a period of 10 minutes. No visible reaction occurred until the ether was *cautiously* distilled from the mixture. The acetal from the hydrolyzed Grignard intermediate was hydrolyzed by refluxing in 20% sulfuric acid solution for 1.5 hours and steam distilling. The crude aldehyde in the distillate was converted to the bisulfite addition compound and then regenerated by a hot solution of sodium carbonate; yield 11 g., 18%.

The same quantities in a second experiment based on Wood and Comley[27] gave 32 g. (52%) of crude aldehyde. After the addition of the ethyl orthoformate, the mixture was stirred for 3 hours, during which time a solid appeared. After standing overnight, the ether was distilled cautiously until the gray mass congealed and separated. The supernatant liquid was decanted into water. The organic layer was decanted and the aqueous layer acidified with sulfuric acid. The resulting organic layer was separated and combined with the other layer. This was added to 200 ml. of 20% sulfuric acid, the mixture steam distilled and the portions of the distillate which gave a sodium bisulfite addition compound were collected.

The third preparation of VII started with 1,2,5,6-tetrahydrobenzaldehyde,[28] according to Diels and Alder.[29] The semicarbazone derivative melted 148–151°; lit. 153–154°.[29] Fifty grams (0.3 mole) of the semicarbazone was hydrogenated at low pressure in 150 ml. of glacial acetic acid with 0.2 g. of 10% palladium-on-carbon. After filtering and distilling the acetic acid, dilution of the residue with 1 l. of water precipitated cyclohexanecarboxaldehyde semicarbazone; m.p. 163–165°. The aldehyde (21.5 g.) was obtained by steam distilling the semicarbazone from 15% sulfuric acid. The conversion from tetrahydrobenzaldehyde to VII was 64%.

The condensation of VII with acetone to 4-cyclohexyl-3-buten-2-one (V) was patterned after Kon.[7] A mixture of 90 g. (0.8 mole) of VII, 280 ml. of reagent-grade acetone, and 280 ml. of 1% sodium hydroxide solution was stirred for 24 hours. The organic layer was separated and combined with the ether extracts of the aqueous layer. After drying over anhydrous potassium carbonate and removing solvents by vacuum, the residue (117 g.) was distilled under nitrogen. About 5% of the aldehyde was recovered. The main fraction (75 g., 62% yield) had the following properties: b.p. 66–70° (0.6 mm.); n^{20}_{D} 1.4846; lit. $n^{19.6}_{\mathrm{D}}$ 1.4842.[7] The semicarbazone melted 164–166°; lit. 168°.[7] There was obtained 3–4% of a slightly lower boiling product: b.p. 61–65° (0.6 mm.), n^{20}_{D} 1.4770, which was mainly the isomeric 4-cyclohexylidene-2-butanone.[7] There was also obtained 7% of 4-cyclohexyl-4-hydroxy-2-butanone.

In several runs the yield of V ranged from 30 to 62%; the yield of 4-cyclohexylidene-2-butanone increased as the yield of V decreased; the yield of 4-cyclohexyl-4-hydroxy-2-butanone varied from 10 to 15%. Both by-products can

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[20] O. Diels, K. Alder and P. Pries, *Ber.*, **62**, 2081 (1929). According to E. van Zuydewijn, *Rec. trav. chim.*, **56**, 1047 (1937), this compound does not react with sulfur dioxide.

[21] C. Weizmann, E. Bergmann and L. Haskelberg, *J. Chem. Soc.*, 391 (1939).

[22] O. Grummitt and E. I. Becker, THIS JOURNAL, **70**, 149 (1948); *Org. Syntheses*, **30**, 75 (1950).

[23] K. Hess and W. Wustrow, *Ann.*, **437**, 256 (1924).

[24] The general procedure of ref. (12) was used.

[25] H. Adkins, L. M. Richards and J. W. Davis, THIS JOURNAL, **63**, 1320 (1941).

[26] R. L. Shriner and R. C. Fuson, "Identification of Organic Compounds," John Wiley and Sons, Inc., New York, N. Y., 3rd ed., 1948, pp. 164–166.

[27] C. E. Wood and W. A. Comley, *J. Soc. Chem. Ind.*, **42**, 429T (1923).

[28] Kindly furnished by Carbide and Carbon Chemicals Corp.

[29] O. Diels and K. Alder, *Ann.*, **460**, 98 (1928).

be converted to the ketone; 15 g. of 4-cyclohexylidene-2-butanone was isomerized by distillation from 0.2 g. of potassium acid sulfate and 0.1 g. of phenol-β-naphthylamine to give 11 g. (74%) of V; n^{20}D 1.4850. Thirty-six grams of 4-cyclohexyl-4-hydroxy-2-butanone was dehydrated by distillation from 0.5 g. of potassium acid sulfate and 0.1 g. of phenyl-β-naphthylamine to give 27.6 g. (86%) of V.

The ketone V was reduced to 4-cyclohexyl-3-buten-2-ol (III) with lithium aluminum hydride.[30] Two grams (0.053 mole) of lithium aluminum hydride (Metal Hydrides, Inc., Beverly, Mass.) mostly dissolved in 80 ml. of anhydrous ether after refluxing for 3 hours. The supernatant liquid was decanted into a 3-necked 500-ml. flask fitted with a stirrer, condenser and addition funnel with calcium chloride tubes. A solution of 13 g. (0.085 mole) of V in 20 ml. of anhydrous ether was added slowly, allowing gentle reflux of the ether. Ten minutes after the addition, 30 ml. of water was added slowly. A thick white sludge formed from which the ethereal layer was decanted. The sludge was washed once with ether and the combined ether extracts were dried over anhydrous potassium carbonate. After removal of the ether, the residue was distilled under nitrogen: 11 g. (85%) boiling 80–81° (0.5 mm.), n^{20}D 1.4778. By liquefying the sludge with concentrated sodium hydroxide solution and further extracting with ether, the yields of III were increased to 90–93%.

Anal. Calcd. for $C_{10}H_{18}O$: C, 77.87; H, 11.76. Found: C, 78.19; H, 11.93.

The *p*-nitrobenzoate ester of 4-cyclohexyl-3-buten-2-ol[26] recrystallized from 95% ethanol melted 54–55°.

Anal. Calcd. for $C_{17}H_{21}NO_4$: N, 4.62. Found: N, 4.69.

Dehydration of 4-Cyclohexyl-3-buten-2-ol (III).—A mixture of 4.7 g. of III, a crystal of potassium acid sulfate and 0.1 g. of phenyl-β-naphthylamine was distilled under nitrogen *in vacuo*. The main fraction, 3.4 g., n^{22}D 1.4950, was redistilled to give 0.8 g., b.p. 50–52° (3 mm.): n^{20}D 1.5045. A quantitative maleic anhydride determination[8] at room temperature for 4 days showed 30.0–30.8% diene. The adduct melted at 137–140°.

***trans*-1-Cyclohexyl-1,3-butadiene (IV).**—4-Cyclohexyl-2-acetoxy-3-butene (VI) was made from III and excess acetic anhydride by the procedure of Marvel and Williams.[8b] From 78 g. (0.51 mole) of III, 120 ml. (1.27 moles) of acetic anhydride and 10 ml. of pyridine there was obtained 94.3 g. (95%) of ester boiling 79–80° (1.5 mm.), n^{20}D 1.4604.

Anal. Calcd. for $C_{12}H_{20}O_2$: C, 73.43; H, 10.27. Found: C, 73.72; H, 10.27.

Through a glass tube, 20 mm. i.d. and 33 cm. long, packed with glass beads and maintained at 475–480° electrically, there was distilled 152 g. (0.78 mole) of VI under 30 mm. pressure during 4 hours. Distillation of the pyrolysate gave 46 g. of product boiling below 80° (1.5 mm.); the residue was recycled through the pyrolysis tube. This recycle yielded 25.8 g. of product; the residue was re-run to give 15.7 g. of distillate and a residue of 15 g. All of the distillates were combined, dried over anhydrous potassium carbonate, and distilled, yielding 75.8 g. (72%) of crude diene and 10.8 g. of residue.

This crude product was fractionated under nitrogen in a 24-inch Stedman column at a reflux ratio of 4/1. There was a low boiling fraction of 10.6 g. (10.1%) at 45–47° (3 mm.); a main fraction of 42.7 g. (40.7%) at 47–48° (3 mm.), n^{20}D 1.4920, $d^{20}{}_4$ 0.8346 ± 0.0002; and a residue of 15 g. (14.3%). The ultraviolet absorption curve of the main fraction was almost identical to that of IV obtained by dissociation of the sulfone (*v.i.*); *cf.* Fig. 1. The quantitative maleic anhydride determination in refluxing toluene for 3 hours showed 96.0–96.1% diene. This determination at room temperature for 4 days gave 94.5–95% diene. A sample of IV was redistilled for analysis.

Anal. Calcd. for $C_{10}H_{16}$: C, 88.16; H, 11.84. Found: C, 88.37; H, 11.81.

3-Cyclohexyl-1,2,3,6-Tetrahydrophthalic Anhydride.—A solution of 1.1 g. (0.0081 mole) of IV, 0.8 g. (0.0081 mole) of maleic anhydride, and 11 ml. of benzene was refluxed for 9 hours. Addition of Skellysolve B and filtering gave 1.4 g. (74%), m.p. 138–140°. This was repeatedly recrystallized from a mixture of 5 volumes of Skellysolve B and 2 volumes of benzene; m.p. 143–143.5°. A mixed melting point with the adduct from which diphenyl had been obtained (*v.s.*) showed no depression.

Anal. Calcd. for $C_{14}H_{18}O_3$: C, 71.77; H, 7.74. Found: C, 72.23; H, 8.00.

1-Cyclohexyl-1,2,3,4-tetrabromobutane.—A solution of 1 g. (0.0074 mole) of IV in 10 ml. of chloroform was added slowly to a solution of 2.3 g. (0.0144 mole) of bromine in 10 ml. of chloroform held at 10–20°. The chloroform was evaporated at room temperature and the residue treated with 95% ethanol until it solidified. This was filtered and the solid recrystallized from 95% ethanol: 1 g. (30%), m.p. 85–93°. Three more recrystallizations raised the melting point to 93–93.5°.

Anal. Calcd. for $C_{10}H_{16}Br_4$: Br, 70.12. Found: Br, 70.03.

1-Cyclohexylidene-2-butene (II).—The residue obtained in the fractionation of 1-cyclohexyl-1,3-butadiene (IV) made from the acetate was distilled under nitrogen; the main fraction boiled 59–60° (4 mm.), n^{20}D 1.5087. The ultraviolet absorption spectrum was almost identical with that of II in Fig. 1. The quantitative maleic anhydride determination in refluxing toluene for 3 hours gave 68.3–73.0% of the calculated conversion of maleic anhydride but only a resinous adduct could be isolated. When the determination was run at room temperature for 4 days, there was 10.1–10.3% reaction. A sample of II was redistilled at 59–60° (4 mm.) for analysis.

Anal. Calcd. for $C_{10}H_{16}$: C, 88.16; H, 11.84. Found: C, 88.12; H, 11.73.

2-Cyclohexyl-2,5-dihydrothiophene-1-dioxide.—A solution of 12 g. (0.188 mole) of sulfur dioxide, 3.4 g. (0.025 mole) of freshly distilled 1-cyclohexyl-1,3-butadiene and 0.1 g. of phenyl-β-naphthylamine in a stainless steel bomb was heated at 75° for 2 hours. Evaporation of the sulfur dioxide gave 4.1 g. of solid. This was recrystallized from Skellysolve B: 2.7 g. (54%) of white needles, m.p. 50–51°.

Anal. Calcd. for $C_{10}H_{16}O_2S$: S, 16.01. Found: S, 16.19.

Five grams of sulfone and 0.1 g. of phenyl-β-naphthylamine were placed in a 50-ml. Claisen flask. The flask was assembled for distillation under nitrogen and reduced pressure. Decomposition set in at an oil-bath temperature of 105° and there was an increase in pressure which continued until distillation started: 3.1 g. (91%) of IV was collected at 93° (47 mm.) to 82° (37 mm.); n^{25}D 1.4925. This was redistilled at 47° (3.8 mm.) into two fractions, both of which had n^{25}D 1.4925 and $d^{20}{}_4$ 0.8346 ± 0.0002. The ultraviolet absorption spectrum is shown in Fig. 1 and the infrared spectrum in Fig. 2.

1-Cyclohexyl-1,3-butadiene Polysulfone.—Sulfur dioxide was bubbled into a solution of 0.8 g. of IV in 2 ml. of alcoholic silver nitrate solution (0.4%) for several hours at 0°. This was kept at 0° overnight and then the viscous solution was poured onto a watch glass. Immediately a white rubbery material separated. After evaporation of the alcohol the rubbery mass was treated with hot water, but it did not become brittle.

1-Cyclohexylidene-2-butene (II) Plus Sulfur Dioxide.—The by-product from the preparation of 1-cyclohexyl-1,3-butadiene from the acetate decomposition was redistilled: n^{20}D 1.5105 and $d^{20}{}_4$ 0.8554. A mixture of 2.1 g. (0.154 mole) of hydrocarbon, 8 g. (0.125 mole) of sulfur dioxide and 0.1 g. of phenyl-β-naphthylamine was heated in the steel bomb at 75–80° for 2 hours. After evaporating the sulfur dioxide the oily residue weighed 2.2 g. When this failed to crystallize, it was distilled at 55° (3.2 mm.) to give 1 g. of recovered II, n^{20}D 1.5120. The ultraviolet spectrum is shown in Fig. 1. When retreated with sulfur dioxide, the physical properties of the recovered II were unchanged.

1-(*p*-Nitrophenyl)-1,3-butadiene.—By the method of Coyner and Ropp[12] 1-(*p*-nitrophenyl)-4-chloro-2-butene was made from 35 g. (0.25 mole) of *p*-nitroaniline, diazotized, and then treated with 33 ml. (0.38 mole) of butadiene. The crude yield was 47 g. (88%) of dark brown oil. This was dehydrochlorinated with methanolic potassium hydroxide to give 30.2 g. (68% based on the *p*-nitroaniline) of crude diene. Crystallization from Skellysolve B gave a product melting 76–77°; lit. 75.0–76.8°.[12] The maleic anhydride adduct melted 166–169°; lit. 170.9–172.0°.[12] The quantitative reaction with maleic anhydride at room temperature for 4 days showed 86.2–86.3% reaction.

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(30) The general procedure of R. F. Nystrom and W. G. Brown, THIS JOURNAL, **69**, 1197 (1947), was followed.

2-(*p*-Nitrophenyl)-2,5-dihydrothiophene-1-dioxide.—A mixture of 12 g. (0.188 mole) of sulfur dioxide, 2 g. (0.114 mole) of 1-(*p*-nitrophenyl)-1,3-butadiene and 0.1 g. of phenyl-β-naphthylamine was heated for 2 hours at 75–80°. The residue (2.1 g.) after evaporation of sulfur dioxide was extracted three times with 20-ml. portions of Skellysolve B at 50° to give 1.2 g. of 1-(*p*-nitrophenyl)-1,3-butadiene. The dark insoluble material melted 107–111° with evolution of gas. Recrystallization from benzene raised the melting point of this sulfone to 119–121° with evolution of gas. A small portion was heated at 130° until gas evolution ceased. Extraction of the residue with 1 ml. of hot Skellysolve B and evaporating the supernatant liquid gave yellow crystals: m.p. 76–78°; a mixed melting point with 1-(*p*-nitrophenyl)-1,3-butadiene was 76–78°.

In a second experiment the mixture was placed in a pressure bottle and allowed to stand for 4 days at room temperature. Evaporation of the sulfur dioxide gave 2.5 g. of residue which was suspended in 15 ml. of benzene and filtered: 1.1 g. (41%), m.p. 110–115° with evolution of gas. This crude sulfone was further purified by dissolving in acetone and precipitating with water: m.p. 125–125.5°.

Anal. Calcd. for $C_{10}H_9NO_4S$: S, 13.40. Found: S, 13.49.

Two attempts to obtain the polysulfone were made. A mixture of 0.4 g. of 1-(*p*-nitrophenyl)-1,3-butadiene and 2.3 ml. of alcoholic silver nitrate (0.4%) was saturated with sulfur dioxide at 0° and allowed to stand 3 days. Evaporation gave 0.3 g., m.p. 70–75°, which on crystallization from Skellysolve B became 77–78°; this was not depressed in a mixed m.p. with the diene.

A greater concentration of sulfur dioxide was attained in the second experiment by allowing a mixture of 1 g. of hydrocarbon, 6 g. of sulfur dioxide and 1 ml. of alcoholic silver nitrate to stand in a pressure bottle for 8 days. About 0.2 g. of hydrocarbon was recovered; the remainder was polymer which did not give a positive qualitative test for sulfur.

1-(*p*-Anisyl)-1,3-butadiene.—1-(*p*-Anisyl)-3-buten-1-ol was made from 24 ml. (0.2 mole) of redistilled *p*-anisaldehyde and the Grignard reagent from 34.5 ml. (0.39 mole) of allyl chloride and 8.5 g. (0.35 atom) of magnesium and the intermediate was hydrolyzed with 60 ml. of saturated ammonium chloride solution.[13] The yield was 30.2 g. (85.5%) boiling 117–118° (1.5 mm.), n^{25}_{D} 1.5353.

Anal. Calcd. for $C_{11}H_{14}O_2$: C, 74.13; H, 7.92. Found: C, 74.24; H, 7.66.

A German patent refers to this alcohol but no constants are given.[31]

The alcohol was dehydrated in the presence of potassium acid sulfate.[14] From 4 g. of alcohol, 0.1 g. of catalyst and 0.1 g. of phenyl-β-naphthylamine there was obtained 2.5 g. (70%) of solid product distilling 93–95° (1.1 mm.). Crystallization from methanol and water gave m.p. 44–46°; lit. 46°.[14] The maleic anhydride adduct melted 142–145°; lit. 145°.[14] The quantitative reaction with maleic anhydride at room temperature for 4 days gave 89.7–90.5% reaction.

1-(*p*-Anisyl)-1,3-butadiene Plus Sulfur Dioxide.—The preparation of the cyclic sulfone was tried twice by the methods described above. Neither at 75–80° for 2 hours nor at room temperature for 3 days was there any indication of reaction with sulfur dioxide. Polysulfone formation was tried with silver nitrate as a catalyst (*v.s.*) in a reaction run for 2 days at 0°. The product contained no sulfur. In all of these experiments the diene polymerized considerably.

***trans*-1-Phenyl-1,3-butadiene Plus Sulfur Dioxide.**—In view of the greater reactivity of the *p*-nitrophenylbutadiene to sulfur dioxide at room temperature than at 75–80°, phenylbutadiene[2] was tried at room temperature. No sulfone formed.

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[31] A. Knorr, German Patent 544,388 (Sept. 26, 1930).

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[CONTRIBUTION FROM THE CHEMICAL LABORATORY OF THE OHIO STATE UNIVERSITY]

Steric Effects. II. Acid-catalyzed Esterification

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The rates of acid-catalyzed esterification of a number of highly branched aliphatic acids are reported. A discussion of the effect of structure on rate is made. It is shown that substitution of hydrogen atoms in the β-position by methyl groups decreases the rate to a greater degree than substitution in the α- or γ-positions.

In a previous publication[2] the acid-catalyzed esterification of aliphatic acids was discussed with the aid of an empirical rule, the rule of six, which stated "the greater the number of atoms in the six position the greater will be the steric effect." As applied to carboxylic acids, the six position is defined by numbering the carbonyl oxygen as one and then counting back into the chain. The six number was defined[2] as the number of atoms in the six position. This paper is concerned with the presentation of further data on the esterification of a number of branched aliphatic acids and a further analysis of the situation.

Experimental

Materials.—*t*-**Butylacetic acid** was prepared by the action of sodium hypobromite on methyl neopentyl ketone.[3] The samples used distilled at 95–96° at 26 mm.

Ethylisopropylacetic acid was prepared from ethyl ethylmalonate by a malonic ester synthesis carried out in the usual manner; b.p. 202.5–203.5°.[4]

t-**Butylmethylacetic acid** was synthesized by the action of alcohol-free sodium methylate on 4,4-dimethyl-3-bromo-2-pentanone.[5] After recrystallizing from a methanol-water solution the acid melted at 51–52°.

t-**Butyldimethylacetic acid** was prepared by reaction of 2,3,3-trimethyl-2-butyl chloride (108 g.) with magnesium and then treating with carbon dioxide in the usual way.[6] There was obtained 15.1 g. of crude acid which after two recrystallizations from petroleum ether yielded 8.3 g. (7.2%) of acid melting at 197–198°.[7]

Neopentylacetic acid was prepared by the Arndt–Eistert synthesis from *t*-butylacetic acid. As reagent for the rearrangement of the diazoketone silver benzoate in triethylamine[8] was employed. The purified acid distilled at 159° at 150 mm.[9]; the over-all yield was 57%.

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[1] Taken from the Ph.D. thesis of Kurt L. Loening, O.S.U., 1951.

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[5] J. G. Aston, J. T. Clarke, K. A. Burgess and R. B. Greenburg, THIS JOURNAL, **64**, 300 (1942).

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[8] M. S. Newman and P. F. Beal, THIS JOURNAL, **72**, 5163 (1950).

[9] F. C. Whitmore, *et al.*, *ibid.*, **63**, 643 (1941).