Hydrolysis of 370 mg. of the same material in a sealed bulb afforded after pumping through a −80° trap into a calibrated volume 2.2 mmoles of gas which analyzed approximately 90% ethylene and 10% dimethyl ether by mass spectrometer. Assuming one mole of ethylene arises from the hydrolysis of one mole of reactant a molecular weight of 186 is obtained.

Anal. Calcd. for $C_4H_{10}BCl_3O$: C, 24.72; H, 5.19. Found: C, 25.11; H, 5.19.

Reaction of Diborane with Allyl Chloride.—To 30.0 g. (0.39 mole) of allyl chloride dissolved in 100 ml. of dry ether was added 0.13 mole of diborane at room temperature. After the addition, the apparatus was swept with dry nitrogen and the product mixture freed of ether solvent by pumping on the vacuum line. The residual oil was fractionated with a 30 theoretical plate spinning band distillation column at a pressure of 1 mm. Three fractions were obtained: A, b.p. 30–40°, wt. 1.0 g.; B, b.p. 76°, wt. 3.1 g.; and C, b.p. 115–118°, wt. 11.3 g.

Fractions A and B reacted violently with water and all three fractions inflamed in the air when placed on cloth or paper. Fraction A was probably a mixture of materials containing γ-chloropropylboron dichloride, but could not be sufficiently purified to give reliable analytical data. Cyclopropane was produced on treating A with aqueous base.

Di-(γ-chloropropyl)-boron Chloride (III).—Fraction B (III, 405 mg.) was hydrolyzed with 10% sodium hydroxide solution in a sealed bulb or the vacuum line to produce 85.4 ml. (S.T.P.) of pure cyclopropane which was identified by infrared and mass spectrometry. The theoretical volume of cyclopropane for the reaction

$$\mathrm{ClB(CH_2CH_2CH_2Cl)_2} \xrightarrow[\mathrm{OH^{\ominus}}]{\mathrm{H_2O}} 2\mathrm{C_3H_6} + 3\mathrm{HCl} + \mathrm{(HO)_3B}$$

was 90 ml. (S.T.P.).

Anal. Calcd. for $C_6H_{12}BCl_3$: C, 35.79; H, 6.01; Cl, 52.83. Found: C, 35.46; H, 5.89; Cl, 53.0.

The nuclear magnetic proton resonance spectrum of fraction B was in agreement with the predicted spectrum of the γ-chloropropyl group. The yield of III based upon diborane was 12%.

Methyl Di-(γ-chloropropyl)-boronite (IV).—To 6.2 g. (0.031 mole) of III contained in a 50-ml. round-bottom flask equipped with a magnetic stirrer, dropping funnel and inert atmosphere was added dropwise with ice-bath cooling 25 ml. of anhydrous methanol. Hydrogen chloride was evolved and after 0.5 hour the methanol was removed on the vacuum line and the residual oil was distilled at reduced pressure, b.p. 68–72° (0.6 mm.), wt. 4.0 g. (65%).

Anal. Calcd. for $C_7H_{15}BOCl_2$: C, 42.70; H, 7.68; Cl, 36.01. Found: C, 42,30; H, 8.02; Cl, 36.09.

Tri-(γ-chloropropyl)-borane (II).—Fraction C (II, 364 mg.) gave 93 ml. (S.T.P.) of pure cyclopropane when hydrolyzed with aqueous 10% sodium hydroxide in the vacuum system; theoretical yield of cyclopropane for the reaction

$$\mathrm{B(CH_2CH_2CH_2Cl)_3} \xrightarrow[\mathrm{OH^{\ominus}}]{\mathrm{H_2O}} 3\mathrm{C_3H_6} + 3\mathrm{HCl} + \mathrm{(HO)_3B}$$

was 100 ml. (S.T.P.).

Anal. Calcd. for $C_9H_{18}BCl_3$: C, 44.40; H, 7.45; Cl, 43.6. Found C, 44.40; H, 7.45; Cl, 43.7

The nuclear magnetic proton resonance spectrum of II was identical to but more intense than that of III.

Cleavage of II by excess 1.0 *M* phenyllithium produced an 84% yield of cyclopropane while heating with water at 100° in a sealed bulb for one week gave only 45% of the theoretical amount although all of the oily II had dissolved.

Treatment of II with three equivalents of silver trifluoroacetate in an inert atmosphere and in diethyl ether at the reflux temperature produced silver chloride but no other isolatable products. Cyclopropane may have been produced and lost from the reaction system. The yield of II was 36% based upon diborane.

N.m.r. Proton Spectra.—Compounds II and III were examined as neat liquids using Varian Model V-4300B nuclear magnetic resonance spectrometer equipped with a 40 megacycle probe. Both II and III exhibited a symmetrical triplet centered at 40 c.p.s. higher field strength than the reference water and a large series of peaks (probably nine or more) centered at 108 c.p.s. higher field strength than water. The triplet represents the hydrogens of the terminal chloromethyl group.

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[CONTRIBUTION FROM THE DEPARTAMENTO DE QUÍMICA DA FACULDADE DE FILOSOFIA, CIÊNCIAS E LETRAS DA UNIVERSIDADE DE SÃO PAULO AND THE INSTITUTO TECNOLÓGICO DE AERONÁUTICA]

The Action of Raney Nickel upon Sulfur Compounds. VI.[1] Formation of Biphenyl Derivatives

BY HEINRICH HAUPTMANN, WOLFGANG FERDINAND WALTER[2] AND CYRO MARINO[3]

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Aromatic thioethers, disulfides, thioesters and thiols yield biphenyl derivatives when heated at 220° with degassed Raney nickel or nickel prepared after Sabatier.

Aromatic disulfides,[4] thioesters and thiols[5] have been found to be transformed into thioethers when refluxed in xylene solution in the presence of Raney nickel degassed at 200°.[4,5] A biphenyl derivative was obtained in these experiments only with 4,4′-dimethoxydiphenyl disulfide, from which a small amount of 4,4′-dimethoxybiphenyl was isolated.[5]

It already has been reported briefly[6] that all the types of sulfur compounds mentioned above as well as aromatic thioethers yield biphenyl derivatives when the reaction is performed at higher temperature. Heating at 220° for 15 hours in the presence of Raney nickel degassed at 200° was found to be suitable for this purpose, but even at 180° biphenyl was an important reaction product, often accompanied by considerable amounts of diphenyl sulfide, especially when phenyl thiobenzoate was the starting material.

Compounds like diphenyl disulfide, diphenyl sulfide and phenyl thiobenzoate which contain only

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(1) Part V, THIS JOURNAL, **77**, 4929 (1955).

(2) Extracted in part from the thesis presented in 1955 to the Faculdade de Filosofia, Ciências e Letras da Universidade de São Paulo by W. F. Walter in partial fulfillment of the requirements for the obtention of the degree of Dr. em Ciências.

(3) Experiments to be included in a thesis to be presented to the Faculdade de Filosofia, Ciências e Letras da Universidade de São Paulo by C. Marino, in partial fulfillment of the requirements for the obtention of the degree of Dr. em Ciências.

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(6) Comm. to the XIV Intern. Congress of Pure and Applied Chemistry, Zürich, July, 1955.

one kind of aromatic radical yielded only one biphenyl compound. From compounds containing two different radicals or from mixtures of two disulfides or two thioesters, three hydrocarbons were obtained, except when one of them was ethane or butane. The isolation of these gaseous hydrocarbons was not attempted, the identification of the remaining two hydrocarbons being considered sufficient to prove the intermolecular character of the reaction. From thiophenol, biphenyl was also formed in low yield, the hydrogen from the thiol groups probably favoring hydrogenolytic desulfurization to benzene.

Besides the biphenyl derivatives, benzene and naphthalene frequently were isolated in varying yields. The formation of these two compounds shows that even the small amount of hydrogen remaining in the Raney nickel after degassing at 200°[5,7] takes part in the reaction.

It seemed important to ascertain whether these small quantities of hydrogen are necessary for the reaction to occur at all. When Raney nickel degassed at 500° (containing only a very small amount of hydrogen (0.5 ml. of hydrogen per gram[7])), was used as desulfurizing agent, the yields of biphenyl derivatives were never lower and sometimes higher than those obtained with Raney nickel degassed at 200° and the amount of naphthalene formed from 2,2′-dinaphthyl sulfide was considerably smaller.

When nickel prepared according to Sabatier,[8] (after degassing at 200° this contains only 0.1 ml. of hydrogen per gram and is therefore practically free from hydrogen[7]) was used, the yields of biphenyl derivatives were of the same order of magnitude as those obtained with the Raney nickel preparations. This leads to the conclusion that the reaction is a topochemical one between the nickel and the sulfur compound, the hydrogen not being essential. Thus finely subdivided nickel powders other than Raney nickel are also suitable for this topochemical desulfurization.[9]

In some of the experiments employing diphenyl disulfide or diphenyl sulfide, *p*-terphenyl could be isolated from the tarry residue which remained after the removal of biphenyl by distillation.

The results obtained are consistent with the idea already advanced[4,5] that during the reactions radicals are formed. While at 140° part of the sulfur–carbon bonds remained intact, at 220° they are all broken and the resulting aryl radicals react with the formation of biphenyl compounds, when still adsorbed at the nickel surface.

Biphenyl derivatives are formed most frequently by reaction of phenyl radicals with aromatic solvents.[10] Several instances of the formation of biphenyl derivatives by the direct reaction of aryl radicals with each other have been reported. In this connection the catalytic reduction of bromobenzene to biphenyl,[11] the electrolysis of phenylmagnesium bromide,[12] the reaction between the same substance, aromatic halides and cobalt chloride,[13] that of bromobenzene and phenyl aluminum diiodide,[14] the desamination of benzenediazonium salts with hypophosphoric acid[15] and the reaction of benzene with hydrogen peroxide in the presence of uranyl salts[16] may be mentioned.

The fact that in several of these cases the reaction occurs at a solid surface emphasizes the analogy between these observations and those reported here.

The isolation of terphenyl is valuable evidence for the homolytic character of the reactions described since formation of this substance is considered a proof of the occurrence of homolytic bond splitting.[10b]

Biphenyl formation in low or modest yield was also observed when mercaptals, thioesters or diphenyl disulfide were heated at 140° in the presence of Raney nickel degassed at 100° (11–12 ml. of hydrogen per gram[5,7]). Here the greatest part of the sulfur compounds is desulfurized hydrogenolytically and biphenyl formation occurs after the hydrogen has been used up. The fact that in this case all carbon–sulfur bonds were split, whereas with nickel degassed at 200° thioethers are obtained, seems to have a bearing on the mechanism of the hydrogenolytic desulfurization. It has been suggested that this reaction involves homolytic splitting of the carbon–sulfur bond with radical formation,[4,5,17] owing to the weakening of the sulfur–carbon bond resulting from the chemisorption of the sulfur atom at the nickel surface.[4] Thus, it has always been understood that the hydrogen does not take part in radical formation.[4,18,19] The different results obtained at 140° with Raney nickel degassed at 100° and at 200° (differing only in their hydrogen content) seem to indicate that the hydrogen does take part in the splitting of carbon–sulfur bonds, perhaps by displacing the radicals from the sulfur. Bonner's[18] important finding that optically active 2-phenyl-2-[phenylmercapto]-propionamide racemizes during the hydrogenolytic desulfurization is not inconsistent with this idea, nor are the observations which Romo,[20] Djerassi,[21] Baker[22] and

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[7] H. Hauptmann and W. F. Walter, *Bol. Fac. Fil. Ciencias Let., Quim.*, **4**, in press.

[8] J. Houben and I. Weyl, "Die Methoden der organischen Chemie," 3rd ed., Vol. 2, Leipzig, 1925, pp. 322 and 475.

[9] Since no experiment at 140° had been performed with Raney nickel degassed at 500° and Sabatier nickel degassed at 200°, diphenyl disulfide and phenyl thiobenzoate were heated in boiling xylene with both. As can be seen from the table, diphenyl sulfide is formed in both cases, the yields being again of the same order of magnitude as those obtained with Raney nickel degassed at 200°.

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TABLE I

Starting material	Heated at °C.	Type of Ni^e	Compounds obtained	Yield,^{g} %	M.p. or b.p. (mm.), °C.
Diphenyl disulfide	140^a	Ra 500	Diphenyl sulfide	87	143–145 (8)^i
	140^a	Sa 200	Diphenyl sulfide	84	159–161 (19)^i
	180^b	Ra 200^f	Biphenyl +	54	67–69^h
			benzene +	18	
			p-terphenyl	0.18	210–212^h
	220^c	Ra 200	Biphenyl	65	68, 5–70^o
	220^c	Ra 500	Biphenyl +	78	69–70^g
			p-terphenyl	0.017	210–212^g
	220^c	Sa 200	Biphenyl	85	69.5–70^{oh}
m,m'-Ditolyl disulfide	140^a	Ra 200	*m,m'*-Ditolyl sulfide	75	174–176 (13)^i
	220^c	Ra 200	*m,m'*-Bitolyl	58	273–278 (690)^l
2,2'-Dinaphthyl disulfide	220^b	Ra 200^f	2,2'-Binaphthyl +	68	183–185^m
			naphthalene	19	80–81^h
	220^b	Ra 500^f	2,2'-Binaphthyl +	81	183–185^m
			naphthalene	8	80–81^h
	220^b	Sa 200	2,2'-Binaphthyl	90	184–185.5^m
Diphenyl disulfide + 2,2'-dinaphthyl disulfide	220^b	Ra 200	2,2'-Binaphthyl +	32	186–187.5^m
			biphenyl +	9	68.5–69^h
			2-phenylnaphthalene +	23	98–102^h
			naphthalene + biphenyl (87 mg.)		
			benzene	11	
Diphenyl sulfide	220^c	Ra 200	Biphenyl	62	69–70^h
	220^c	Ra 500	Biphenyl +	75	68.5–69.5^h
			p-terphenyl +	6	210–212^h
			diphenyl sulfide	6	145–150 (10)^i
	220^c	Sa 200	Biphenyl	61	67–69.5^h
Ethyl *p*-tolyl sulfide	220^c	Ra 200	4-Ethyltoluene +	21	157–160 (712)^n
			p,p'-bitolyl	10	118–120^o
Diphenyl sulfide + 2,2'-dinaphthyl sulfide	200^b	Ra 200	Biphenyl	63	67–68^h
			2,2'-Dinaphthyl	63	185–187^h
			2-Phenylnaphthalene	25	97–99^h
			Benzene	7	
Phenyl thiobenzoate	140^a	Ra 500	Diphenyl sulfide	74	126–130 (5)^i
	140^a	Sa 200	Diphenyl sulfide +	76	120–123 (3)^i
			phenyl thiobenzoate	7	52–54^h
	180^d	Ra 200	Biphenyl +	37	69–70^h
			diphenyl sulfide	36	162–170 (23)^i
	220^c	Ra 200	Biphenyl	56	69–70^h
	220^c	Ra 500	Biphenyl	57	68–70^h
	220^c	Sa 200	Biphenyl +	58	66–69^h
			diphenyl sulfide	18	160–165 (23)^i
Phenyl thioacetate	220^c	Ra 200	Biphenyl +	47	67–69^h
			toluene	10	106–109 (713)^p
2-Naphthyl thiobenzoate	220^b	Ra 200	2,2'-Binaphthyl +	50	184–185^n
			2-phenylnaphthalene +	18	99–101.5^q
			naphthalene + biphenyl (30 mg.)		39–80
Thiophenol	220^c	Ra 200	Biphenyl	23	69–70^h

[a] Heated for 15 hours in boiling xylene. [b] Heated for 15 hours in a sealed tube without solvent. [c] Heated for 15 hours in a sealed tube in the presence of benzene. [d] Heated in open flask for 15 hours in a stream of nitrogen. [e] Ra 200 = Raney nickel degassed at 200° *in vacuo;* Ra 500 = Raney nickel degassed at 500° *in vacuo;* Sa 200 = Sabatier nickel degassed at 200° *in vacuo.* [f] The use of benzene was avoided even in the preparation of Raney nickel. [g] When several compounds were isolated the yields were calculated as if every compound was formed by an independent reaction; in this manner the distribution of the different radicals is indicated. An idea of the over-all yields and of the total recuperation of the radicals is given by the sum of their yields in all compounds isolated. [h] The melting points were not depressed by admixture of authentic material. For characterization transformed into: [i] sulfone, [k] dinitrobenzene, [l] biphenyl-3,3'-dicarboxylic acid, [m] picrate, [n] tetrabromoethyltoluene, [o] 4-[*p*-tolyl]-benzoic acid, [p] benzoic acid, [q] 2-phenyl-1,4-naphthoquinone.

Badger[19] made during the hydrogenolytic desulfurization of hemithioketals, polythiosalicylides and thiophene derivatives.

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Experimental[23]

Three representative experiments are described.

Reaction of Raney Nickel Degassed at 200° with *m,m'*-Ditolyl Disulfide at 220° in Benzene.—Raney nickel (65 g.) was degassed for 2 hours at 200° and 3 mm. and then trans-

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[23] The melting points were taken with a Kofler melting point apparatus.

ferred with some benzene to a Carius tube; 6.68 g. of *m,m'*-ditolyl disulfide was added and the sealed tube was heated for 15 hours at 220°. The contents of the tube was extracted exhaustively with boiling benzene, concentrated at atmospheric pressure using a short Widmer column, and the residue was distilled. It yielded 2.88 g. (58%) of a yellowish liquid, b.p. 273–278° (690 mm.); reported[24] for *m,m'*-bitolyl, b.p. 286–287° (713 mm.), which was oxidized with alkaline 2% potassium permanganate to biphenyl-3,3'-dicarboxylic acid, m.p. 357–360° (reported[25] 357–358°).

Reaction of Raney Nickel Degassed at 200° with 2,2'-Dinaphthyl Sulfide and Diphenyl Sulfide at 220°.—Raney nickel (53 g.) was transferred with benzene to a Carius tube and the solvent was evaporated on the water-pump, while the nickel was held in place by means of a magnet. The dry nickel was degassed by heating for 2 hours at 200° and 2 mm. and 5.05 g. of 2,2'-dinaphthyl sulfide and 3.46 g. of diphenyl sulfide were added under a stream of nitrogen. After heating for 15 hours at 220° the tube was connected to a gas buret and opened. No gas formation was observed. It next was connected to two traps, one at 0° and the other at −40°, and then heated at 95° for some hours. Only traces of a white crystalline substance appeared in the first trap; in the second 0.18 g. of a colorless substance was collected, was identified as benzene by nitration to 1,3-dinitrobenzene, m.p. 89–90° (reported[26] 89–89.5°). The contents of the Carius tube was then extracted with twelve 100-ml. portions of boiling xylene. The extract was concentrated and the residue fractionated. By repeated recrystallizations of the fractions 1.53 g. of biphenyl (m.p. 67–68°), 1.62 g. of 2-phenylnaphthalene (m.p. 97–99°) and 2.56 g. of 2,2'-binaphthyl (m.p. 185–187°) were isolated. The melting points of these substances were not changed by admixture of authentic material. A sulfur free white crystalline product, m.p. 100–120°, 0.27 g., which obviously was a mixture of several substances, and 0.63 g. of a sulfur-containing resin could not be purified or identified.

Reaction of 2,2'-Dinaphthyl Disulfide with Nickel Powder Prepared after Sabatier.—Nickel powder obtained by reducing 20 g. of nickel oxide[27] at 320° for 4 hours in a hydrogen stream was suspended in benzene and transferred to a Carius tube. It then was dried and degassed at 200° and 4.34 g. of 2,2'-dinaphthyl disulfide added as described above. The tube was heated at 220° for 15 hours. By extraction with xylene 3.13 g. (90%) of 2,2'-binaphthyl was obtained which melted at 184.5–185° (from alcohol) and was identified by transformation into the picrate (m.p. 184°).

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[CONTRIBUTION FROM THE DEPARTMENT OF BIOCHEMISTRY, YALE UNIVERSITY]

The Absolute Configuration of Dihydroxyacetone Phosphate Tritiated by Aldolase Reaction[1]

BY IRWIN A. ROSE

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The configuration of enantiomorphic tritiated dihydroxyacetone phosphate molecules is established by relation to the stereospecificity of reaction of glycolic acid oxidase and lactic dehydrogenase with glycolic acid. It is concluded that the enzyme–substrate compound formed between aldolase and dihydroxyacetone phosphate is attacked by either a proton or an aldehyde approaching from the same direction.

Isotopic and kinetic evidence has been presented indicating that in the aldol condensation of dihydroxyacetone phosphate (DHAP) with aldehyde, catalyzed by the enzyme aldolase, there occurs a preliminary reaction between DHAP and enzyme to form an enzyme–DHAP compound.[2–5] This intermediate can either react with an aldehyde to form the free condensation product and enzyme or split to free enzyme and DHAP which, when the reaction is performed in tritiated water, acquires one atom of tritium joined to the carbinol-carbon. No radioactivity is found in the condensation product even upon prolonged incubation of the complete system in tritiated water. It has been noted[5] that all products formed by condensation of DHAP with aldehydes and all compounds subject to aldol cleavage by this enzyme have the L-configuration at the third carbon of the phosphoketose.

In the present work, it is of interest to determine whether the tritium atom of the DHAP is placed in a sterically equivalent position to carbon four of the condensation product. This will be called the L-configuration and its enantiomorph, the D-configuration. The absolute configuration has relevance to the mechanism of the aldolase reaction when considered in the following light. Although the chemical structure of the activated DHAP cannot be given in detail, the labilization of one particular hydrogen atom suggests that of a sterically restrained anion, bound firmly to the protein, with an electronic distribution between that of the enol- and keto-forms. Depending on the mechanism of attack of the protein upon the DHAP, the proton may have been either ejected or withdrawn from the α-carbon. In either case it must be in rapid equilibrium with hydrogen ions of the medium (there is no isotope effect)[5] so that the reversal of this process results in labelled DHAP. In the cleavage of the condensation product the resulting aldehyde may likewise be ejected or withdrawn from the α-carbon. If the latter, the subsequent dissociation of the aldehyde does not require the simultaneous dissociation of the enzyme–DHAP compound as shown by the independent turnover of the two "triose parts" of fructose 1,6-diphosphate when incubated with aldolase.[4] Regardless of the mechanism, if both aldehyde and proton follow the same reaction line in their approach to or departure from the intermediate, the absolute configuration of the tritiated DHAP would be L. If, however, they approach along opposite paths,

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