crystals of the original preparation. The hydrazide which we prepared from alfalfa and which we identified as citric trihydrazide was seeded in this way with some of Nelson's compound, which explains the high melting point and its agreement with the value obtained by him.

Alfalfa therefore contains citric, malic and malonic acids in notable amounts, the citric being present in largest quantity, malic in about two-thirds the quantity of the citric, and malonic in about one-fourth that of the citric.

The authors wish to acknowledge their indebtedness to Dr. E. B. Meigs of this Bureau, and to Mr. E. K. Nelson and Mr. R. M. Hann of the Bureau of Chemistry, for valuable assistance rendered in the prosecution of this work.

Summary

Citric, malic and malonic acids, in notable amount, have been identified in green alfalfa plants.

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[Contribution from the Chemical Laboratory at Iowa State College]

THE REACTION BETWEEN ARYL SULFONATES AND ORGANOMAGNESIUM HALIDES

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Introduction

Alkyl esters of aromatic sulfonic acids differ markedly in several respects from the corresponding esters of carboxylic acids. These differences underlie the extensive applicability of alkyl sulfonates as alkylating agents. The alkyl group of sulfonic esters can be attached directly to practically all elements commonly found in organic compounds.

Ferns and Lapworth[1] have indicated the different reactivities of the alkyl esters of sulfonic and carboxylic acids towards amines, alcoholates, phenates and the Grignard reagent in the following diagrammatic manner.

$$RSO_3O \,\vdots\, \text{Alkyl} \qquad\qquad RCO \,\vdots\, \text{O Alkyl}$$

The dotted lines show the place of fission when the above-mentioned reagents are used. The ready alkylating action of sulfonic esters can be correlated with that of alkyl halides, but it appears to be highly unique in the sense that no other alkyl esters of oxygen or sulfur acids behave in the same way towards certain compounds, in particular the Grignard reagents.

The reaction between alkyl esters of aromatic sulfonic acids and RMgX compounds [$2p\text{-}CH_3C_6H_4SO_2O\text{-Alkyl} + 2\ RMgX = 2R\text{-Alkyl} + (p\text{-}CH_3C_6H_4SO_3)_2Mg + MgX_2$] permits the preparation of an unusually wide

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[1] Ferns and Lapworth, *J. Chem. Soc.*, **101**, 273 (1912).

variety of hydrocarbons, and of hydrocarbon derivatives where the substituents are unreactive towards the Grignard reagent.[2]

With a view to extending this work, a study has been made of the reaction between aryl esters of aromatic sulfonic acids and the Grignard reagent. As might have been predicted, in part, the aryl sulfonates are decidedly unlike the alkyl sulfonates. It is not possible to introduce an aryl group or to arylate by this reaction. Instead of hydrocarbons sulfones and phenols are obtained according to the following reaction: $CH_3C_6H_4SO_2O\text{-Aryl} + RMgX \longrightarrow CH_3C_6H_4SO_2R + \text{ArylOMgX}$.

This is in agreement with other reactions of aryl sulfonates. As a rule, the aryl esters of sulfonic acids have much in common with the aryl esters of carboxylic acids. Splitting reactions of both types of esters involve the removal of the -O-aryl group. Aryl sulfonates are decidedly less active than alkyl sulfonates, and when reaction does occur between the aryl esters and amines, alcoholates and phenates it is the -O-aryl and not the -aryl group that is removed.[1,3] An apparent exception is the reaction between phenyl-*p*-toluenesulfonate and sodium ethylate whereby phenetole and sodium *p*-toluenesulfonate are formed. This indicates an arylating action, but Ferns and Lapworth[1] explain the formation of phenetole by the following successive reactions: $CH_3C_6H_4SO_2OC_6H_5 + NaOC_2H_5 \longrightarrow CH_3C_6H_4SO_2OC_2H_5 + C_6H_5ONa \longrightarrow CH_3C_6H_4SO_2ONa + C_6H_5OC_2H_5$. Supporting evidence for this interpretation is found in some work of Phillips[3] on the dependence of rotatory power on chemical constitution.

The reactions between sulfonic esters and the Grignard reagent emphasize strikingly the danger of making broad generalizations from a few experiments. First, esters of aromatic sulfonic acids differ from the corresponding esters of aliphatic sulfonic acids.[4] Second, alkyl esters of a given sulfonic acid undergo different reactions with the same RMgX compound.[5] Third, aryl Grignard reagents differ both in kind and extent of reaction from alkyl Grignard reagents.

[2] Gilman and Beaber, THIS JOURNAL, **47**, 518 (1925). References to all earlier work on this reaction are contained in this article or in the papers to which it refers.

[3] Phillips, *J. Chem. Soc.*, **123**, 44 (1923).

[4] The ethyl ester of ethylsulfonic acid gives a small amount of ethylbenzene and much ethylphenyl sulfone when treated with phenylmagnesium bromide (Ref. 1). The formation of ethylbenzene is characteristic of alkyl esters of aromatic sulfonic acids and of dialkyl sulfates (Ref. 2). The formation of sulfones is characteristic of aryl sulfonates.

[5] Using the term alkyl in its broadest sense, we find that menthyl benzenesulfonate and bornyl *p*-toluenesulfonate with RMgX compounds give largely menthene and camphene, respectively (Ref. 2).

Furthermore, Kenyon, Phillips and Turley [*J. Chem. Soc.*, **127**, 399 (1925)] have just reported a very unusual reaction. They found that the *p*-toluenesulfonic ester of optically active ethyl lactate when treated with phenylmagnesium bromide, for example, gave ethyl α-bromopropionate and not the expected ethyl α-phenylpropionate. Studies in progress in this Laboratory on the reactions of sulfonic esters suggest a different mechanism from that which they proposed.

Some differences between alkyl and aryl Grignard reagents have already been reported.[2] The results of the present study show virtually no reaction between aryl sulfonates and alkyl Grignard reagents unless long refluxing at elevated temperatures with a large excess of RMgX compound is used. Under these conditions some phenol is obtained. Significant quantities of sulfur compounds are formed, and although their constitutions have not yet been established, they are not esters or sulfides or sulfoxides. In all probability they are sulfones formed by molecular rearrangements as a result of the drastic conditions employed.

The reactions between butyl- and *iso*-amylmagnesium bromides and phenyl *p*-toluenesulfonate indicate that the differences between alkyl and aryl Grignard reagents are of degree and not of kind. The formation of butyl- and *iso*-amyl-*p*-tolylsulfides may be due to the reduction of the corresponding sulfones. RMgX compounds, particularly those which have an alkyl group, effect reductions, and under decidedly forced conditions it is possible to reduce a sulfoxide to a sulfide. Sulfones, however, are unusually resistant to such reducing action.[6]

A later paper will contain an account of the mechanism of reaction between sulfonic derivatives and the Grignard reaction, with special emphasis on the possible intermediate addition to the sulfonyl (S=O) group.[7] In this connection it is interesting to note that amides of sulfur acids undergo virtually no reaction with RMgX compounds.

Experimental Part

Preliminary experiments showed that the reaction between an aryl ester and the Grignard reagent took place to a limited extent only in ether as a medium. Accordingly, the ester dissolved in dry toluene was added to the Grignard reagent prepared in ether, most of the ether was then distilled, and the resulting mixture was refluxed during stirring for various periods of time. The temperature of the mixture was generally between 105° and 110°.

The reaction products were hydrolyzed by dil. hydrochloric acid. Any solid that separated was worked up independently of the solutions. The toluene layer was separated, washed with water, dried with calcium chloride or potassium carbonate and then fractionated in a vacuum.

All solid sulfones that had been described previously were identified by mixed-melting-point determinations.

The yields of phenols are not reported. Such yields would be of doubtful value, for studies now in progress on the oxidation of RMgX compounds show that a considerable quantity of phenol is obtained when an aryl Grignard reagent is refluxed in benzene or toluene. Blank experiments

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[6] Hepworth and Clapham, *J. Chem. Soc.*, **119**, 1188 (1921).

[7] Unpublished results show that the aryl esters of silicon, phosphorus, arsenic and boron acids behave like sulfonic esters towards RMgX compounds.

made under the general conditions followed with alkyl Grignard reagents showed that no phenol was formed by the "acid hydrolysis" of phenyl-*p*-toluenesulfonate subsequent to extensive refluxing in toluene and ether.

Preparation of the Di-*p*-toluenesulfonate of 4,4′-Dihydroxybiphenyl ($CH_3C_6H_4SO_2OC_6H_4C_6H_4OSO_2C_6H_4CH_3$).—A solution of 37.4 g. (0.67 mole) of potassium hydroxide in a small volume of water was added slowly to a mixture containing 127 g. (0.67 mole) of *p*-toluene-sulfochloride and 62 g. (0.33 mole) of 4,4′-dihydroxybiphenyl. After stirring for several hours and then warming on a water-bath to complete the reaction, the mixture was filtered and washed several times with water. Crystallization from benzene gave 24.5 g. or a 21.2% yield[8] of ester melting at 189–190°.

Anal. Calcd. for $C_{26}H_{22}O_2S_2$: S, 12.95. Found: 13.04, 13.30.

TABLE I

REACTION OF ESTERS WITH GRIGNARD REAGENT

Unless otherwise stated, equivalent molecular proportions of ester and Grignard reagent[a] were used in each experiment. The yields of products are based on the amount of ester originally used and make no allowance for the ester recovered.

Ester[b]	Moles	RX compound	Hours of refluxing	Sulfone formed	Yield G.	Yield %
Phenyl	0.5	Bromobenzene	5	Phenyl-*p*-tolyl	50.5	43.5
Phenyl	.26	*p*-Bromotoluene	13	Di-*p*-tolyl	29	45.4
Phenyl	.1	*p*-Bromo-anisole[c]	5	*p*-Anisyl-*p*-tolyl[d]	21.5	82
Phenyl	.1	α-Bromonaphthalene	30	α-Naphthyl-*p*-tolyl[e]	20	71
o-Cresyl	.5	Bromobenzene	15	Phenyl-*p*-tolyl	49.5	42.7
Di-*p*,*p*′-biphenyl	.06	Bromobenzene[f]	8	Phenyl-*p*-tolyl	17	61
Phenyl	.5	Ethyl iodide[g]	2	......	..	..
Phenyl	.1	*n*-Butyl bromide[h]	30	Unidentified	7	..
Phenyl	.08	*iso*-Amyl bromide[i]	30	Unidentified	6.5	..
Phenyl	.4	Chlorocyclohexane[j]	20	....	..	..
Phenyl	.5	Benzyl chloride[k]	5	Unidentified	10.5	..

[a] Actually more than the equivalent amount of magnesium and RX compound was used in each experiment. The extra quantities used were calculated from the yields of some Grignard reagents as determined by Gilman and McCracken, THIS JOURNAL, **45,** 2462 (1923).

[b] The *p*-toluenesulfonates were used.

[c] In this experiment 0.2 mole of *p*-bromo-anisole and 0.2 mole of magnesium were used.

[d] The *p*-anisyl-*p*-tolylsulfone, when recrystallized from alcohol and benzene, melted at 159°. The melting points recorded in this paper are uncorrected.

Anal. Calcd. for $C_{14}H_{14}O_3S$: S, 12.21. Found: 12.03, 12.05, 12.07.

[e] The α-naphthyl-*p*-tolylsulfone crystallized from 95% alcohol in white plates; m. p., 119°.

Anal. Calcd. for $C_{17}H_{14}O_2S$: S, 11.35. Found: 11.19, 11.39.

Several unsuccessful attempts were made to prepare this sulfone from α-naphthylmagnesium bromide and *p*-toluene-sulfochloride. See Wedekind and Schenk, *Ber.*, **54B,** 1604 (1921).

[f] 0.12 Mole of phenylmagnesium bromide was used in this experiment; 3.5 g. or a 31.5% yield of 4,4′-dihydroxybiphenyl was obtained.

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[8] It is certain that the yield can be improved by employing a technique worked out at a later time (Ref. 2).

[g] Forty g. or 32% of the phenyl-*p*-toluenesulfonate was recovered. The apparently intractable oil which was also obtained was not studied in this experiment. No ethylbenzene was formed.

[h] In a first run 0.5 mole of ester and 0.55 mole of *n*-butyl bromide were used. The products obtained after 15 hours' refluxing in toluene were phenol, 58% of the original ester and 0.2 g. of a sulfur compound; m. p., 109°.

In a second run 0.1 mole of ester and 0.5 mole of *n*-butyl bromide were refluxed in toluene for 30 hours. The products obtained were 2 g. or 2.1% of phenol, 3 g. or 17% of *n*-butyl-*p*-tolyl sulfide and 7 g. of a sulfur compound which when, crystallized from alcohol, melted at 109°. This compound was unaffected after being refluxed for 20 hours with concd. alcoholic potassium hydroxide solution. An acetic acid solution of it also withstood a protracted digestion with a liberal excess of 30% hydrogen peroxide.

Anal. Found: S, 17.60, 17.48.

[i] In addition to phenol and 2 g. of di-*iso*-amyl there were obtained a 13% yield of *iso*-amyl-*p*-tolyl sulfide, b. p. 150–155° (15 mm.); 1.5 g. of a sulfur compound, b. p. 190–195° (15 mm.); and 6.5 g. of a sulfur compound, m. p. 128–128.5°. (0.5 mole of *iso*-amylmagnesium bromide was used.)

The *iso*-amyl-*p*-tolyl sulfide was not analyzed. However, a 93% yield of *iso*-amyl-*p*-tolyl sulfide was obtained from *p*-thiocresol, *iso*-amyl bromide and sodium hydroxide. This sulfide boiled at 150° (16 mm.).

The sulfur compound distilling at 190–195° (15 mm.) is undoubtedly *iso*-amyl-*p*-tolylsulfone. *iso*-Amyl-*p*-tolylsulfone prepared from sodium *p*-toluenesulfinate distilled at 177–178° (5 mm.) and 195–197° (16 mm.). Neither of these compounds has been analyzed, but they will be reported in the later paper concerned with the mechanism of reaction.

The sulfur compound melting at 128–128.5° was not analyzed. It is unaffected by hot alcoholic potassium hydroxide and by 30% hydrogen peroxide in acetic acid.

[j] 90% of the ester was recovered. In addition, about 3 g. of phenol and 6 g. of an apparently intractable oil were obtained.

[k] In addition to 54.4% of unchanged ester, there was obtained 10.5 g. of a sulfur compound; m. p. 176–177°, when crystallized from benzene.

Anal. Found: S, 16.05, 16.25.

When the reaction mixture of a like run was refluxed in ether for five hours, 88.5% of ester was recovered.

The experiments with cyclohexylmagnesium chloride and ethylmagnesium iodide were carried out early in the study when the chief aim was to determine whether any arylating action took place.

Conclusions

The absence of hydrocarbons proves that no arylating action occurs. However, it is possible to prepare a wide variety of alkyl-aryl compounds in good yield by the reaction between alkyl-*p*-toluenesulfonates and arylmagnesium halides.[2]

Although aryl sulfones can be obtained in satisfactory yields, considering the amount of recovered ester, the method does not compare favorably with standard syntheses of sulfones. It should find some use in the preparation of "abnormally oriented" sulfones because of the ready accessibility of varied aryl esters and arylmagnesium halides.

Summary

Aryl esters of *p*-toluenesulfonic acid when refluxed in toluene with arylmagnesium halides give sulfones and phenols. The reaction under like conditions with a large excess of alkylmagnesium halides gives some phenol, the aryl-alkyl sulfide and unidentified compounds which are probably sulfones formed by rearrangement.

AMES, IOWA

[CONTRIBUTION FROM THE POLARIMETRY SECTION, BUREAU OF STANDARDS, UNITED STATES DEPARTMENT OF COMMERCE[1]]

RELATIONS BETWEEN ROTATORY POWER AND STRUCTURE IN THE SUGAR GROUP. X.[2] THE CHLORO-, BROMO- AND IODO-ACETYL DERIVATIVES OF LACTOSE

BY C. S. HUDSON AND ALFONS KUNZ

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When it was shown in Part I[3] that the rotation of the end asymmetric carbon atom of a halogeno-acetyl aldose is approximately a constant quantity, namely, one of the coefficients A_F, A_{Cl}, A_{Br} or A_I, for nearly all the aldoses, it was stated that the value of A_{Cl} for chloro-acetyl lactose that was derived from Bodart's record of the specific rotation of this substance in chloroform ($[\alpha]_D = +72$) "is somewhat low and should be reëxamined." This revision has now been made and it has been found that Bodart's rotation is much too low, the correct $[\alpha]_D$ being $+84$, in good agreement with the calculated value. The specific rotation of carefully purified bromo-acetyl lactose has likewise been re-measured and found to be 109°, which is somewhat larger than previous determinations (105°) and agrees closely with the calculated value. The rotation of pure iodo-

TABLE I

THE VALUE OF THE QUANTITY A, THE ROTATION OF THE END ASYMMETRIC CARBON ATOM, FOR CHLORO-, BROMO- AND IODO-ACETYL LACTOSE

Lactose	Mol. wt.	$[\alpha]_D^{20-5}$ in $CHCl_3$	$[M]_D$	Rotation[a] of end carbon	A for corresponding derivative of	
					Cellobiose	Glucose
α-Chloro-acetyl	655	+ 84	+ 55,000	+38,100(A_{Cl})	+39,000	+40,200
α-Bromo-acetyl	699	+109	+ 76,200	+59,300(A_{Br})	+58,300	+60,700
α-Iodo-acetyl	746	+137	+102,200	+85,300(A_I)	+85,200	+87,800[b]

[a] $A = [M]_D - 16{,}900$. This number is the value of $B_{lactose}$ from the rotations of the alpha and beta forms of lactose octa-acetate (see Part I, p. 464).

[b] This value, which is somewhat larger than that recorded in Part I (+85,600) is obtained from the $[\alpha]_D$ of iodo-acetyl glucose in chloroform (+237), recently published by D. H. Brauns [THIS JOURNAL, **47**, 1280 (1925)].

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[1] Published by permission of the Director of the Bureau of Standards.

[2] Part IX was published in THIS JOURNAL, **47**, 872 (1925).

[3] *Ibid.*, **46**, 462 (1924); see also some corrections, *ibid.*, **46**, 2592, Footnote 5 (1924).