

bined rate at which the two secondary alcohol groups in the ethylcellulose had been esterified. Mathematical analysis of this rate curve showed that the data agreed very closely with a unimolecular, fairly rapid tosylation of 0.151 mole of hydroxyl superimposed on a slow tosylation of 0.245 mole. Comparison with the independent data in (1) made it clear that the ethylcellulose had 0.151 mole of free hydroxyl groups in the

second position and 0.245 mole in the third. These values were probably more accurate than those quoted in (1).

4. The first order rate constants for the tosylation of unsubstituted hydroxyl groups in the ethylcellulose were in the approximate ratio of 2.3 for the second, 0.07 for the third and 15 for the sixth position.

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The Relationship between the Method of Preparation, the Distribution of Substituents and the Solubility in Water or Alkali of Methyl and Ethyl Ethers of Cellulose¹

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The ready solubility in organic solvents of the ethylcellulose just studied³ made it possible to follow the rates of tosylation and of oxidation with lead tetraacetate in homogeneous systems. These estimations, together with the selective iodination of the tosylated derivative and the periodate oxidation of the derived ethylated glucose and glucoside mixtures, determined the average distribution of the alkoxy and hydroxyl groups between the second, third and sixth positions of the cellulose structure. It was obvious that the shape of the reaction-rate plot observed for a heterogeneous mixture of pyridine, tosyl chloride and an insoluble less highly alkylated cellulose could not be reliably connected with the different amounts of hydroxyl group in the second and third positions. Although this information could probably be obtained from the corresponding mixture of ethylglucosides, the present work was restricted to adapting the analyses for primary hydroxyl and glycol groups to some water or alkali soluble methyl- and ethyl-celluloses.

Ethers (A), (B) and (C) (Table I) were high grade technical materials prepared in heterogeneous reactions from alkali-cellulose, while (E) and (F) were similar products. Ether (D)⁴ was made

(1) Presented before the Division of Cellulose Chemistry at The Atlantic City meeting of the American Chemical Society, September, 1941.

(2) Abstracted from a thesis submitted by J. F. Mahoney to the Faculty of the Massachusetts Institute of Technology in partial fulfillment of the requirements for the degree of Doctor of Philosophy, June, 1941. Present address: Merck and Company, Rahway, New Jersey.

(3) Mahoney and Purves, *THIS JOURNAL*, **64**, 9 (1942). This article contains all data quoted for ether (A).

(4) The authors wish to thank Dr. S. H. Bass, of the Dow Chemical Company, for Methocels (B) and (C). The former had the lot

by ethylating cellulose homogeneously dispersed in aqueous trimethylbenzylammonium hydroxide.⁵

TABLE I
CHARACTERISTICS OF CELLULOSE ETHERS EXAMINED

Ether ^a	Alkoxy ^b	Substitution	Average chain length ^b	Solubility at 0°C.
A	OEt 48.5%	2.48	120	Org. solvents
B	OMe 30.5	1.85	150	Water
C	OMe 10.7	0.588	210	Caustic soda
D	OEt 14.7	0.583	300	Water
E	OEt 27.6	1.20	425	Water ^c
F ^d	OEt 17.5	0.707	...	Caustic soda

^a All data for Ether (A) are quoted from the preceding article.³ ^b By Staudinger's viscosity method (see text). ^c Some granularity. ^d Both (E) and (F) were described as of relatively high viscosity.

The Average Chain Length of Ethers B-E.—Two-gram samples were acetylated for three days at room temperature with a mixture of 60 ml. of pyridine and 20 ml. of acetic anhydride. The products were purified by precipitation from acetone solution into water, and after drying had alkoxy contents of 24.3, 7.62, 13.0 and 20.9%, corresponding to basic molecular weights of 236, 239, 200 and 259, respectively. Viscosities were measured in glacial acetic acid at 25°³ and the Staudinger η_{sp}/c quotients became constant at concentrations of 0.03 to 0.01 mole per liter or less. The η_{sp}/c values were 35.0, 51.9, 60.1 and 110, and the average chain lengths quoted in Table I were derived from them by making the doubtful assumption that Staudinger's K_m constant was 10×10^{-4} in all cases.

number M-453 and a viscosity of 26 centipoises in 2% aqueous solution at 20°. The latter, number MX-287, had a viscosity of 34 centipoises for a 2% solution in 4% caustic soda. We are also indebted to Dr. L. H. Bock, of the Röhm and Haas Company, for ether (D) and to Dr. H. M. Spurlin, of the Hercules Powder Company, for specimens (E) and (F) (Samples X2167-12 and X2167-14). The ash content of the samples was low.

(5) Bock, *Ind. Eng. Chem.*, **29**, 985 (1937). This article reviewed the literature, and discussed the solubility in water of alkylated celluloses in relation to the distribution of the alkyl groups.

TABLE II

Ether (1)	Tosylation				Iodination					
	Hours (2)	S, % (3)	Alkoxy, % (4)	Moles tosyl ^a (5)	S, % (6)	Alkoxy, % (7)	I, % (8)	Moles tosyl ^a (9)	Moles iodine ^a (10)	Moles ^a sum (11)
(B)	100	7.80	19.0	0.737	2.71	20.6	22.5	0.234	0.492	0.726
	200	8.37	18.2	0.824	3.79	19.4	20.7	.347	.478	0.825
(C)	100	10.4	5.30	1.12	4.04	5.84	30.4	.397	.752	1.15
	200	12.1	4.45	1.55	7.01	4.82	24.4	.822	.721	1.54
(D)	100	8.77	8.56	0.840	1.64	9.43	32.6 ^b	.143	.714	0.857
	200	10.9	6.96	1.28	5.43	7.62	25.9	.585	.700	1.29
(E)	100	10.4	13.7	1.28	5.57	15.0	22.6	.635	.650	1.29
	200	11.1	12.8	1.47	6.71	13.7	20.6	.823	.636	1.46
(F)	100	9.97	9.21	1.07	3.84	9.86	28.1	.381	.703	1.08
	200	10.6	8.71	1.21	4.77	9.49	26.3	.499	.693	1.19

^a Per anhydroglucose unit. ^b Individual analyses 33.0 and 32.1% iodine.

Ethylcellulose (F) failed to give an acetate which dissolved completely in glacial acetic acid.

Estimation of Primary Hydroxyl Groups in Ethers B-F.—The carefully dried material (4 g.) was gently agitated at room temperature with anhydrous, redistilled pyridine (150 ml.) containing pure *p*-toluenesulfonyl chloride (50 g.). All the ethers swelled in the reagent but only (C) and (E) eventually dissolved to give very viscid, almost homogeneous, solutions. After four to five days, about one-third of each mixture was worked up and the partly alkylated, partly tosylated cellulose was analyzed, iodinated and analyzed again by methods already described.³ Another third of each mixture was similarly examined after seven to nine days of tosylation. The partly tosylated samples (B) to (F) were tough, rubbery, or fibrous materials which were pale brown in color and were more or less completely dispersed by shaking in the moist state with acetone. Reprecipitation and extraction with various liquids failed to give white products. As qualitative tests revealed no nitrogen and only a trace of chlorine, it was concluded that the color was due to tenaciously adsorbed impurities too small in amount to affect the analytical data substantially.

Closely concordant duplicate analyses were obtained throughout and the averages are listed in Table II. The sulfur and alkoxy content of the partly tosylated products (columns 3 and 4) were used to calculate the molar amount of tosyl substitution. An independent calculation from the alkoxy content with the assumption that tosylation had not changed the alkoxy substitution checked excellently. Column (5) gives averages from the two methods of computation. The molar substitution of tosyl groups and iodine in the fully iodinated products (columns 9 and 10) were also calculated independently from the iodine and sulfur contents with practically the same numerical results by both methods. Comparison of the data in column (5) with the sum of the tosyl plus iodine substitution (column 11) showed that the figures approached the theoretical equivalence within 2% except in the shorter tosylation of ethyl cellulose (C), where the difference was within 3%. Such mathematical cross checks on the internal consistency of the data were peculiarly valuable in the present instance, where amorphous products recovered from heterogeneous reactions were being studied.

Inspection of the figures for the iodine substitution (column 10) showed that the esterification of the primary hydroxyl groups in each of the original alkylated celluloses was complete within the shorter period of tosylation. The latter reaction therefore proceeded normally in a heterogeneous system. No definite explanation was available for the apparently systematic discrepancy of 0.01 to 0.03 mole between the data for the two periods but it was possibly due to the increasing adsorption of small amounts of impurities during tosylation. In this event, the larger figure in each pair was the more accurate. The average, however, was used in subsequent calculations (Table III, column 3).

TABLE III

Ether (1)	—Moles hydroxyl groups ^a —			—Moles glycol groups ^a —				
	Total (2)	Pri- mary (3)	Sec- ond- ary ^b (4)	Found (5)	H ² /4 (6)	H-1 (7)	H/2 (8)	Primary alkyl/ s-alkyl (9)
(A)	0.52	0.12	0.40	0.01	0.04	0.00	0.20 ^c	0.55
(B)	1.15	.49	0.66	.32	.11	.00	.33	.38
(C)	2.41	.74	1.67	.83	.70	.67	.84	.79
(D)	2.42	.71	1.71	.75	.73	.71	.86	1.00
(E)	1.80	.64	1.16	.52	.34	.16	.58	0.43
(F)	2.29	.70	1.59	.74	.63	.59	.80	0.73

^a Moles per glucose residue. ^b Sum (H) of hydroxyl groups in second and third positions. ^c Since $H = 0.151 + 0.245$ in this case,³ the accurate values were 0.037 instead of 0.04 and 0.15 instead of 0.20.

Estimation of Glycol Groups in Ethers B-F.—Since these derivatives were all insoluble in acetic acid, the lead tetraacetate method previously used for ether A was abandoned in favor of a periodate oxidation carried out exactly as described for the ethylated glucose mixture derived from ether (A).³ One-half to one millimole quantities (0.1 to 0.2 g.) were shaken with 25 ml. of water before the known volume of standard, buffered sodium periodate solution was added. Ethers (B) and (D) dissolved in the water, ether (C) dissolved after five days of oxidation, but the dissolution of (E) and (F) was still incomplete when the experiment was terminated. When solution had apparently reached the maximum possible, aliquots were withdrawn and used to follow the amount of periodate consumed. The results were plotted in Fig. 1.

The final data on the alkylated celluloses were summarized in Table III, in which the total moles of unsubstitution (column 2) were obtained by subtracting the total alkoxy substitution (Table I) from the number three. Iodination of the partly tosylated specimens (Table II, column 10) gave the moles of hydroxyl groups exposed in the sixth or primary positions of the original materials (Table III, column 3). The difference between columns 2 and 3 (column 4) corresponded to the sum H of the unsubstituted, secondary hydroxyl groups in the second and third positions. The value of H was believed to be correct to within one or two units in the second decimal place. Whenever a glucose residue had both these positions unalkylated, a glycol unit occurred which was estimated by the periodate technique (column 5).

The alkylation of cellulose after the fibrous structure had been sufficiently swollen or dispersed by a suitable environment should expose all portions of the macromolecule uniformly to the reagent. In this case the alkoxy, or the remaining hydroxyl groups, would be scattered at random but with uniform average density throughout the length of the cellulose chain. If the second positions contained x hydroxyl groups and the third positions $H - x$, the probability that a given glucose residue remained unalkylated in both positions was $x(H - x)$. Although the value of $x(H - x)$ could not be calculated from a knowledge of H alone, the product did not decrease quickly from the maximum of $H^2/4$ until x became small in respect to $H/2$ which was unlikely with alkylated celluloses. The good agreement between the glycol groups found and calculated (column 6) for the ether D strongly supported the conclusion that alkylation in a quaternary ammonium base, at least with the sample examined,⁶ had distributed the substituent uniformly throughout the chains.^{5,6}

Another possible assumption concerning the mode of alkylation was that substitution in either the second or third position greatly depressed the reactivity of the adjacent hydroxyl group in the same glucose unit. Consideration showed that no unsubstituted glycol occurred until the amount of hydroxyl groups distributed between the two positions, H , exceeded one mole. In low alkylated celluloses, H naturally lay between one and two moles and the probability of the glycol coincidence was $x + (H - x) - 1$ or $H - 1$. The

(6) Cf. Compton, *THIS JOURNAL*, **60**, 2823 (1938).

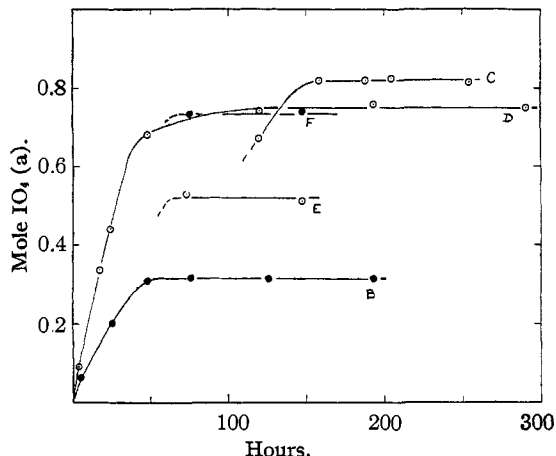


Fig. 1.—Periodate oxidation of cellulose ethers B to F, (a) moles per glucose residue.

$H^2/4$ and the $H - 1$ probabilities for the ether (D) were too similar for a reliable distinction to be made between them. Those for ether (A) were so small that they afforded only indecisive support to the assumption that alkylation of one position hindered alkylation of the adjacent one. If the effect was real, the difficulties encountered in preparing completely alkylated celluloses become more understandable⁷ and the diethyl glucose isolated in at least 40% yield from an ether of the (A) type⁸ was either the 2-6 or the 3-6 derivative.

When alkali cellulose was etherified by an organic halide or sulfate, microscopic studies and general considerations⁹ showed that the readily accessible regions in the fibers were easily and extensively substituted. The hydrophobic shell so formed then hindered the progress of the reaction to the interior of the micelles. Such a highly heterogeneous mechanism would tend to produce a partly substituted cellulose in which the glucose residues were either completely substituted or completely unsubstituted. The corresponding probability of glycol groupings, $H/2$ (column 8), was closely checked by the values actually found for the technical methyl celluloses (B) and (C) and was approached by the similar products (E) and (F). It was therefore extremely probable that these four ethers consisted of cellulose chains highly alkylated through some portions of their length and almost unsubstituted in others. As alkylation proceeded, a point was reached

(7) The article by Johnston, *ibid.*, **63**, 1043 (1941), includes a review of the literature.

(8) Hess, *Ann.*, **506**, 595 (1933).

(9) Lorand and Georgi, *THIS JOURNAL*, **59**, 1166 (1937), reviewed the literature dealing with the mechanism of this reaction.

when the product became more soluble in the reagent and the reaction therefore became more homogeneous. The data for the highly substituted ether (A) showed that in this later stage the earlier non-uniform distribution of substituents along the cellulose chains was levelled out.

The ratio of the alkoxy groups present in the sixth position to those in the second and third positions (Table III, column 9) was readily obtained after subtracting the data in column 3 from unity and those in column 4 from two. Since the alkylation resulting in ether (D) was essentially a homogeneous process, the ratio of unity obtained in this case indicated that the intrinsic reactivity of the primary hydroxyl groups in alkylation was approximately twice as great as the average for the two secondary ones. The difference was not so large as in the case of esterification with tosyl chloride⁸ but was much the same as the ratio deduced for the deacetylation of cellulose triacetate to the acetone soluble stage.¹⁰ Decreases in the ratio with the other alkylated celluloses from 1 to 0.5 were quite consistent with the idea that a rapid initial alkylation of superficial primary groups was overtaken by the alkylation of superficial secondary ones during the period when the progress of both reactions to the interior of the micelles was hampered by diffusion difficulties. This explanation, however, failed to account for the ratios of less than 0.5 which were observed for ethers (B) and (E). The reactivity of the primary position was obviously restricted in an additional way at certain stages of heterogeneous alkylation, perhaps owing to delay in the dissolution of hydrogen bonds involving primary hydroxyl groups in the interior of the micelles. Shielding of this position during methylation was postulated in other cases.¹¹

A striking feature of the data in Table I was that the ether (D) had practically the same degree of substitution as the ether (C) but the solubilities in caustic soda and water were the reverse of what might have been predicted from the average chain lengths. Differences in degree of substitution or of polymerization were, therefore, not major factors accounting for the difference in solubility. The change from methyl to ethyl in passing from (C) to (D) was also immaterial because the methyl analog of (D) was soluble in water when similarly prepared in a quaternary am-

monium base.⁵ The average distribution of substituents between the primary and secondary positions of the glucose residues was very similar in the two cases (Table III) but, as shown above, the distribution along the length of the cellulose macromolecule was very different. By elimination, therefore, the insolubility of (C) in water was connected with the fact that the hydroxyl groups were for the most part bunched in localized patches along the chains. The hydrogen bonds in such largely unsubstituted patches were apparently strong enough and numerous enough to hold separate chains together in spite of the solvent action of water, although alkali caused them to disintegrate. Water solubility appeared at a much higher degree of heterogeneous alkylation (Table I, B and E) in products which had an unexpectedly low ratio of primary to secondary substitution (Table III, column 9). It has already been suggested that the low ratio was due to hydrogen bonding, involving primary hydroxyl groups in the less substituted interior of the micelles. Apparently water solubility occurred when a suitable number of the bonds had been disrupted in the progress of the alkylation.

Another deduction from the theories outlined above was that the dispersion of cellulose in the sodium-copper complex¹² or as the sodium derivative in liquid ammonia¹³ was sufficient to render methylation almost as homogeneous a process as alkylation in a quaternary ammonium base. This inference followed from the fact that in the two former cases the products became soluble in water in a substitution range (0.8-0.9) only slightly higher than that possessed by water soluble derivatives of the type (D) (0.6-0.7).

Summary

1. Five water or alkali soluble methyl or ethyl celluloses were partly esterified with *p*-toluenesulfonyl chloride, and the amount of primary alcoholic groups each contained was determined by iodinating the esters. The estimation proceeded normally in spite of the heterogeneous character of the reactions.

2. Subtraction of the primary alcoholic groups from the total present in the original alkylcelluloses left the quantity *H*, which was equal to the average sum of the two secondary alcoholic groups in the glucose unit of cellulose. When alkylation occurred with uniform average density

(10) Cramer and Purves, *THIS JOURNAL*, **61**, 3458 (1939).

(11) Heddle and Percival, *J. Chem. Soc.*, 249 (1939).

(12) Traube, Piwonka and Funk, *Ber.*, **69**, 1483 (1936).

(13) Schorigin and Makarowa-Semljanskaja, *ibid.*, **69**, 1713 (1936).

along the length of the cellulose macromolecules, the maximum frequency of completely unsubstituted glycol units was calculated to be $H^2/4$. When alkylation was localized in intermittent lengths of the cellulose chain, the probable frequency of glycol units was $H/2$. The actual occurrence was determined by oxidation with sodium periodate.

3. Alkylation of cellulose dispersed in a quaternary ammonium base gave a water soluble product with a glycol content close to $H^2/4$ while the technical, heterogeneous alkylation of alkali cellulose to the same degree (substitution 0.6) resulted in water insoluble products with a glycol count of $H/2$. The other characteristics of the two products were so similar that the insolubility of the latter in water could only be connected with the

highly non-uniform substitution of the macromolecules. All the data gave very strong support to the views of Lorand and Georgi [THIS JOURNAL, 59, 1166 (1937)] on the mechanism of the alkylation of alkali cellulose, and to those of Bock [*Ind. Eng. Chem.*, 29, 985 (1937)] on the type of distribution required for solubility in water.

4. In a homogeneous medium, the primary hydroxyl groups in cellulose were alkylated approximately as fast as both secondary groups together. This ratio was smaller in heterogeneous alkylations and was less than the calculated minimum for water soluble products prepared in this way. The inference was that the primary hydroxyl groups were partially shielded from the reagent at this stage of the alkylation.

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The Direct Diazotization of Nitrobenzene

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In 1904, Bamberger and Wetter¹ observed that a very small amount of benzene-1-azo-naphthol-2 (0.38 g. from 20 g. nitrobenzene) was formed when a petroleum ether solution of nitrobenzene and 2-naphthol were shaken in the cold for several days with finely powdered sodium amide. In an attempt to prepare *o*- and *p*-nitroaniline, Bradley and Robinson² allowed sodium amide to stand with nitrobenzene (1.3 moles) in an enamelled steel cylinder for six months. One of the substances isolated in small yield corresponded in composition to a nitrohydroxyphenazine. Williams³ found that benzene-1-azo-naphthol-2 was formed in fair yield by adding nitrobenzene to a solution of 2-naphthol in an excess of potassium amide dissolved in liquid ammonia. It is with this reaction that the present paper is concerned.

Nitrobenzene reacts with an excess of sodium amide or potassium amide in liquid ammonia at -33° or at room temperatures to give a deep reddish-brown solution from which an apparently dark colored precipitate slowly deposits. Nitrogen is evolved at both temperatures, very roughly in the ratio of one mole per two moles of nitrobenzene. Such ammonia solutions when evapo-

rated to dryness leave an explosive residue that is rather sensitive to shock. Hydrolysis of the reaction product before the evaporation of the liquid ammonia gives an oil from which nothing has been obtained. Similarly, little or nothing of definite characteristics was obtained by the reaction of excess potassium amide with a number of other nitro compounds.

If nitrobenzene is added to a solution of 2-naphthol in an excess of alkali amide in liquid ammonia, benzene-1-azo-naphthol-2 is formed in yields up to about 30% of the theoretical, with the simultaneous evolution of nitrogen. When sodium amide and nitrobenzene are allowed to react in liquid ammonia at -33° until formation of nitrogen has practically ceased, and 2-naphthol is then added, approximately the same yield of dye is obtained. The diazo compound responsible for dye formation is thus either produced with evolution of nitrogen, or the latter gas arises from an independent reaction. The optimum yields of dye result when about six moles of amide are used per mole of nitrobenzene.

Since sodium benzenediazotate does not react with sodium amide and 2-naphthol under the conditions of these experiments, it is obvious that normal benzenediazoic acid or its sodium salt is

(1) Bamberger and Wetter, *Ber.*, 37, 629 (1904).

(2) Bradley and Robinson, *J. Chem. Soc.*, 1262 (1932).

(3) Williams, unpublished work, Stanford University, 1930.