THE BROMINATION OF PARA-CRESOL IN THE PRESENCE

OF

STRONG ACIDS.

Thesis by Edward W. Hart.

In partial fulfilment of the requirements for the Degree of Bachelor of Science in Chemical Engineering.

> California Institute of Technology September 20, 1924 Pasadena California.

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INTRODUCTION

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The aim of this work has been to determine whether or not the formation of an oxonium compound of a cresol would change the directing influence of the hydroxyl radical.

So far as was ascertainable from the literature, there has been no work of just this type performed previously. However, the results of Vorlander(1), who studied the directing influence of the amino group in salts, Kendall(2), Maass and McIntosh(3), McIntosh(4), and Kendall and Carpenter(5), all of whom have described addition compounds between acids and organic oxygen containing compounds, were read with interest and profit. The report of the work of Kendall and Carpenter was of particular value because of the presentation of data pertaining to the formation of addition products, containing an oxonium structure, between phenols and sulphuric acid.

These two investigators studied the formation of addition products between (eight) classes of substances grouped in the following manner:

First system

Weak phenol - Strong acid

Second system

Weak phenol - Weak acid

Third system

Strong phenol - Weak acid

Fourth system

Strong phenol - Strong acid

They found that as the phenol became stronger, with respect to the acid, the tendency to form addition products grew less. Naturally then they obtained the best yields of addition product formation in the system of weak phenol and strong acid. Under this system, they experimented with adding 100% sulphuric acid to various phenols.

It was desired to use para-cresol for the work in hand because of the comparative freedom in this phenol from conflicting directing influences, so the results of Kendall and Carpenter , obtained when sulphuric acid was added to para-cresol, were studied with particular care. They found that two addition products could be isolated, both of them being stable at their points of fusion. These two compounds have the formulae 2 C_7H_7OH , H_2SO_4 (m. p. 11.0°) and C_7H_7OH , 2 H_2SO_4 (m.p. 93.5°). The flatness of the maximum of the freezing point curve in the case of the former compound indicates that it is largely dissociated into its components on fusion, but the form of the curve for the latter addition product, together with its surprisingly high melting point, makes it evident that the compound is very stable. The data for the freezing point curve of this latter compound is copied and presented herewith:-

% C_H_OH 56.0 48.7 34.7 28.6 21.6 16.2 12.5 39.5 33.8 78.2 57.8 40.2 Т 24.0 57.3 84.1 91.9 93.4 90.9

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OUTLINE OF WORK.

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A series of preliminary experiments was undertaken in order to determine the nature of the substances to be worked with. Weights of para-cresol and 100% sulphuric acid were taken corresponding to the percentages indicated in the data given above. It was found that the addition product crystallized out unless a large excess of acid were present.

Having found the most suitable proportions of cresol and acid to use and still keep the mixture liquid, the first experiment was started. A large excess of sulphuric acid was present, about 180 % excess, but sulphonation was not feared because of a specific note in the report of Kendall and Carpenter, which stated that "sulphonation itself rarely took place at the temperature of the experiment (their experiment).

"Sulphonation is a slow process, even at high temperatures. Hence, at the freezing point of the mixture, (93.5[°]) its progress during the course of the experiment was generally negligible entirely.

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"Sulphonic acids decompose on fusion and have no definite freezing points."

After the addition product had been formed it was brominated and an attempt was made to discover the nature of the brominated product. A vacuum distillation was started but the amount of the yield proved to be insufficient to permit of this. Crystals which had formed in the neck of the distilling flask were removed and their melting point taken. This temperature did not correspond to the melting point of the 2-brom para-cresol, the 3-brom para-cresol, or the 3,5-dibrom para-cresol(see data sheet). It was thought probable that sulphonation had occurred, so another experiment was started.

For this second experiment, the quantities of para-cresol and 100% sulphuric acid were so chosen that the acid was in excess of the amount required theoretically by only about 7%. The addition product was formed and brominated just as in the previous experiment, and the brominated addition product was decomposed. The decomposition produced two phases, an oil phase, which solidified on standing, and an aqueous phase. It was thought that the oil or solid phase would prove to be 2-brom para-cresol(m.p. $55^{\circ}-56^{\circ}$), but on investigation it proved not to be. Its melting point did not correspond to that of 2-brom para-cresol and the melting point of its benzoate did not correspond to that of 2-brom-tolyl-benzoate. Likewise the melting points of the solid and its benzoate did not match the melting points of the corresponding products of 3-brom para-cresol and its benzoate or 3,5-di-brom para-cresol and its benzoate.

The aqueous phase was then looked to to reveal some information on the result of bromination of the addition product. It was found that sulphonation had taken place and that the aqueous phase contained at least one sulphonic acid. It was necessary to decompose this sulphonic acid, and, this having been done, the resulting solution was worked up and subjected to a vacuum distillation. From the results, which will be found below, of this distillation it was concluded that the entering bromine had gone to the three position with possibly slight traces of bromine appearing in the two position and in the three-five(di-brom) positions. Again it was thought that sulphonation had taken place.

Now if sulphonation took place first and the sulphonic acid group were directed to the three position, as it would be if the oxonium group were not present, any bromine, entering subsequently, would be directed to the five position, due to the combined influences of the sulphonic acid group and the hydroxyl group. This brominated product would yield then, on decomposition of its sulphonic acid, a three-brom para-cresol. Again, if sulphonation occurred first but the sulphonic acid group had entered the two position, that is, if the directing influence of the hydroxyl group had weakened sufficiently to permit of the directing influence of the methyl group predominating, any bromine entering subsequently would appear in the six position due to the combined influences of the sulphonic acid group and the methyl group. This compound would yield two-brom para-cresol on decomposition of its sulphonic acid.

Sulphonation must have either preceded bromination or taken place simultaneously with it, because in this experiment there was not enough sulphuric acid present to permit of the formation of the oxonium group and a sulphonic acid group on the same molecule. Since the greater part of the brom-cresol was discovered with a sulphonic acid group attached, there are but two possible explanations. Sulphonation either took place when the sulphuric acid was added in the first place or else a state of equilibrium existed between an

addition compound and the free cresol which was disturbed by the addition of bromine in such a way as to further the production of the sulphonic addit. Bromine may catalyze sulphonation reactions similar to

However, no conclusions can be drawn as to the directing influence of the addition product because either it never was formed, or, if it were formed, the addition of bromine destroyed it. It is known, though, that the addition product was formed because it crystallized out slightly before any bromine was introduced. Therefore the latter view must be accepted.

In order to preclude altogether the possibility of sulphonation a third experiment was undertaken in which hydrochloric acid was used to form the addition product. Para-cresol was used again, but, instead of 100% sulphuric acid, a saturated solution of hydrochloric acid in glacial acetic acid was used. The process of forming the addition product and of brominating it after it was formed was identical with that of the two previous experiments. After bromination the reacting mixture was distilled under atmospheric pressure, to remove the acetic acid and thus decompose the addition product. This having been done the remaining solution was subjected to a vacuum distillation. From the result of this vacuum distillation it was concluded that 3-brom para-cresol was the principal product, but that there might be traces of 2-brom para-cresol and 3,5-di-brom paracresol. (See data sheet). It necessarily follows that if an oxonium compound were formed, such formation did not change the directing influence of the hydroxyl group sufficiently, at least, to cause it to direct an entering bromine atom to any position different from

iodine.

that one to which it would naturally direct such an entering atom. Here again though, there is the possibility that an equilibrium existed between hydrochloric acid in the addition product and hydrochloric acid in acetic acid solution, and that the addition of bromine produced conditions that favored the return of the hydrochloric acid to solution in the glacial acetic acid.

DETAILS OF EXPERIMENTS



The apparatus for the three experiments was the same. The main part of the apparatus was that in which the addition product was formed and in which it was brominated. This part of the apparatus is represented in the figure.

A is the reaction chamber, a three necked flask, in which the

Figure 1.

para-cresol is found.

B is a separatory funnel through which the 100% sulphuric acid, and following this, the liquid bromine, is introduced.

C is a small motor for rotating the stirrer D.

D is a glass stirrer.

E is a flask containing water in which hydrobromic acid gas is absorbed.

F is a glass tube for conducting hydrobromic acid gas into flask E.

G is a mercury seal which keeps the moisture in the air from entering the flask.

H and I are calcium chloride drying tubes.

The 100% sulphuric acid used in the first two experiments was made from calculated quantities of 95% sulphuric acid and 24% fuming sulphuric acid. (100 gms.95% acid to 93.5 gms.24% fum.acid)

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First Experiment

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Weight para-cresol (C7H70H)16.2 gms.Weight 100% sulphuric acid (required theoretically)29.5 gms.Weight 100% sulphuric acid (actually used)83.8 gms.Per Cent. excess 100% sulphuric acid184.1 %Weight bromine24.0 gms.

The acid was run through the separatory funnel into the flask containing the cresol with constant stirring. During the addition of the acid a moderate $(20^{\circ}30^{\circ})$ rise in temperature took place. After the addition of the acid was complete and the contents of the flask had been cooled, the bromine was run in very slowly, also with constant stirring. These two precautions precluded the possibility of the occurrence of a high local excess of bromine, and thus prevented the formation of any di-brom substitution product. The addition of the bromine required about two hours. Stirring was continued for about another two hours until a drop of bromine that had settled out on the bottom of the flask disappeared.

The high concentration of sulphuric acid was decreased by the addition of ice(10 grams) until the heat thus generated ceased

to aid or rather further bromination, as evidenced by the re-appearance of striations in the hydrobromic acid flask in greater quantity than at any previous time. Bromination must have started again because hydrobromic acid gas is insoluble in either 100% sulphuric acid or para-cresol, and so the hydrobromic acid gas that came over after the addition of ice could not have been boiled out of solution but must have been produced as the result of the presence of heat in the flask.

The solid, that precipitated on the addition of more water (150 cc.)and subsequent standing, was filtered and dried. An attempt at a vacuum distillation of this solid was unsuccessful because of an insufficient quantity. Fine, white, needle-like crystals collected in the neck of the flask, however, and these were removed for a melting determination. The melting point was 83° C. These crystals were not those of 2-brom para-cresol, 3-brom para-cresol, or 3,5-di-brom para-cresol. What they were was not determined.

No attempt was made to work up the filtrate because it was feared that, contrary to the statement by Kendall and Carpenter, a mono- or perhaps a di-sulphonic acid had formed, due to the great excess of 100% sulphuric acid present.

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Second Experiment

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Weight para-crescl(C7H7OH)	81.2	gms.
Weight 100% sulphuric acid (required theoretically)	14 7. 6	gm s .
Weight 100% sulphuric acid (actually used)	158.9	gms.
Per. Cent. excess 100% sulphuric acid	7.6	×
Weight bromine	120.0	gms.
Weight brom-substitution product (theoretical yield)	140.5	gm s .
Weight brom-substitution product((actual yield)	7 8.0	gms.
Per Cent yield (theoretical)	55.5	%
Per Cent yield (actual) (because of removal of solution) (for tests throughout the work)	58.2	80

The procedure in this experiment was similar to that in the first experiment. The proportions of cresol and acid, however, in this experiment, were such as to cause crystallization to begin soon after the acid was first introduced into the flask. The contents of the flask became hot during the addition of acid, but a few drops of bromine were added anyway to prevent further crystallization of the addition product. The flask was then cooled and the rest of the bromine added at the rate of about 130 drops a minute. After the addition of the bromine was complete, the liquid in the flask was allowed to stand quiet for about a half hour, in which time it solidified to an orange crystalline(needle-like) cake.

This cake dissolved in 200 cc. of water, portions of it dissolving more rapidly than others, with the evolution of heat.

The addition of water in excess of that needed to dissolve the cake caused the formation of a white cloudy liquid. The cloudiness disappeared on standing and an orange oil appeared at the bottom of the flask. Water(2 1.) was added until it no longer produced a cloudiness in the solution. The oil was allowed to settle and on standing over night it crystallized. A melting point determination of these crystals was made, and the melting point found to be 49°- 50°C. It was thought that this was 2-brom para-cresol $(m. 0.55^{\circ} - 56^{\circ}C)$ with impurities present that lowered the melting point. It was, therefore, decided to prepare the benzoate(ref.6) of these crystals, take its melting point and check it against that of pure 2-brom-tolyl benzoate. Before preparing the benzoate, the impure crystals were purified by dissolving in aqueous sodium hydroxide, filtering and again acidifying the filtrate. A test of the crystals obtained showed these purer crystals to have a melting point of about 82°C.

Melting point of crude bromination product from solution44°-45°C.Melting point of same after purifying $79^{\circ}-85^{\circ}C.$ Melting point of the benzoate $100^{\circ}-101^{\circ}C.$ Melting point of benzoate of pure 2-brom para-cresol $74^{\circ}-75^{\circ}C.$

From the lack of coincidence in the melting points of the crystals and pure 2-brom para-cresol, and in the melting points of the benzoate of the crystals and pure 2-brom-tolyl benzoate, it was concluded that the crystals were not those of 2-brom paracresol, 3-brom para-cresol, or 3,5-di-brom para-cresol. It was then decided to see what could be learned from an investigation of the filtrate.

The filtrate was first extracted with ether. The amount of oil so obtained was inappreciable and insufficient to permit of a distillation in vacuo. Previous to extracting with ether, enough sodium carbonate was added to the filtrate to convert all the substate ions (SO_4^{-}) into acid sulphate ions (HSO_4^{-}) . If more sodium carbonate were added a precipitate, probably a sodium sulphonate, would come down. The only reason the sodium carbonate was added at all at this point was to decrease the solubility of ether in the filtrate. When the ether layer, containing what oil there was, had been removed, the water layer was boiled, to remove the ether that it had in solution, and enough more sodium carbonate was added to convert all the acid sulphate ions into sodium sulphate. No precipitate of a sodium sulphonate came down at this point. It was necessary to cool a sample of the solution in ice before crystallization started in the sample. On evaporating the filtrate down to about one half precipitate its initial volume, however, a copious came down. The precipitate that came down was filtered off, crystallized from alcohol, dried and tested qualitatively for sulphur and bromine, both of which were found to be present.

The fact that sulphur was found present coupled with the fact that the yield of brom-cresol, following bromination, was so slight, would seem to indicate that sulphonation had taken place. Therefore it was decided to decompose the sodium sulphonate and see whether or not the resulting compound would be a brom-crescl, and if it were one to determine which one. The decomposition was effected by distilling the sodium sulphonate in sulphuric acid solution with superheated steam (ref. 7).



Figute 2.

A is the steam can.

B is the superheating coil.

C is the thermometer indicating superheat temperatures.

D is the distilling flask.

E is the oil bath.

F is the condenser.

G is the receiving flask.

200° C. Temperature of superheated steam

190° C. Temperature of oil bath

Weight of sodium sulphonate191.0 gms.Per cent. yield (calculated from amount of p-cresol used)87.7 %Per cent. yield (")(considering samples removed)90.0 %Weight of crude brom - cresol96.1 gms.Per cent. yield (calculated from amount of p-cresol used)71.9 %Per cent. yield (calc. from amount of sodium sulphonate)77.8 %

The crude brom - cresol was subjected to a fractional distillation, and, after the second fraction, the following separation was obtained.

First fraction		1050	-	10 7º	at	23	mm.		
	and	108°	-	110°	at	25	mm.	58.	1 gms.
Second fraction		10 7 0	-	108 ⁰	at	23	mm.		
	and	110 ⁰	-	112 ⁰	at	25	mm.	11.	1 gms.
Third fraction		108 ⁰	-	124 ⁰	at	23	mm.		
	and	112 ⁰	-	124 ⁰	at	25	mm.	6.	8 gms.
Fourth fraction		124 ⁰	-	154 ⁰	at	25	mm.	_2.	0 gms.
Total yield								78.	0 gms.
Per cent. yield								58.	2 %

In this experiment it is beyond all doubt that sulphonation did take place to a very great extent. The only move left now was to perform the experiment in the absence of any sulphuric acid. This was done and will be considered immediately below. * * * * *

THIRD EXPERIMENT.

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Weight	of	p - cresol	50. 0	gms.
Weight	of	glacial acetic acid	283.5	gms.
Weight	of	hydrochloric acid (theoretically required)	33.6	gms.
Weight	of	hydrochloric acid (actually used)	50.4	gms.
Weight	of	bromine	73.6	gms.
Weight	of	brom-substitution product (theoretical)	86.0	gms.
Weight	of	brom-substitution product (actual)	7 8.0	gms.
Per cen	nt.	yield	90.7	%

The method employed in this experiment, for forming the addition product, was just the same as that used in the two previous experiments. However, instead of adding on sulphuric acid to the cresol, hydrogen chloride in glacial acetic acid was used.

The hydrochloric acid was prepared by running commercial concentrated hydrochloric acid into concentrated sulphuric acid. The gas was then bubbled through a wash bottle filled with sulphuric acid and passed into glacial acetic acid at about 4° C.

As the acetic acid solution of hydrochloric acid was run into the reaction flask, the mixture was stirred. The hydrochloric acid was followed immediately by bromine, also added with stirring. The reacting mixture was kept cold, during the addition of both the acid and the bromine, by an ice-salt bath.

The solution was next distilled under atmospheric pressure until the temperature reached 134° C. At this point the temperature held steady and no distillate came over. The liquid remaining in the flask was transferred to a Claissen flask and subjected to a vacuum distillation. After four fractions the following separation was obtained.

First fraction	$104^{\circ} - 112^{\circ}$	25 mm.	60.0 gms.
Second fraction	112 [°] - 118 [°]	25 mm.	1.5 gms.
Third fraction	118 [°] - 145 [°]	25 mm.	2.0 gms.
Fourth fraction	145° - 148°	25 mm.	3.0 gms.
Fifth fraction	148° - 152°	25 mm.	5.0 gms.
Sixth fraction	152° - 156°	25 mm.	6.5 gms.
Total yield			78.0 gms.

From the results of the fractional distillation, it must be concluded that the greatest part of the bromine entered in the 3 position. It would also seem probable that some of the bromine had gone toward forming the 3,5 di-brom p-cresol, and that a small part of the bromine had gone to the 2 position. (See page 19, data sheet)

* * * SUMMARY

Para-cresol has been brominated in the presence of two different amounts of 100% sulphuric acid and in the presence of a saturated solution of hydrochloric acid in glacial acetic acid. The resulting bromsubstitution product, in each case, has been found to be the same as that which should result theoretically if neither inorganic acid had been present, namely 3 brom p-cresol. It has been explained that because of unexpected sulphonation in the first two experiments, and because of the also unexpected catalyzing action of bromine in the second and third experiments, the results are not conclusive evidence as to whether the presence of the two, strong, inorganic acids had any influence on the positions taken by the entering bromine or not.

At this point it might be suggested that more conclusive results might be obtained by using strong acids other than sulphuric and hydrochloric, or by changing the group to be introduced and using the same or different acids for the formation of the addition products. By doing the former, sulphonation would be prevented, on the one hand, and by doing the latter, the catalyzing influence of bromine would be removed.

And now in final conclusion, the author wishes to thank Prof. H. J. Lucas not only for his invaluable aid in selving questions concerning the chemistry of the problem, but also for many helpful suggestions concerning the mechanical technique involved in the work.

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2 brom para-cresol	£		m.p.	55° - 56° C			
			b.p.1	$40^{\circ} - 140.5^{\circ}$ C	at	25	mm.
3 brom para-cresol		÷	m.p.	1 7° - 18° C			
			b.p.	108° - 109°C	at	25	mm.
3,5 di-brom para-cresol			b.p.	$155.5^{\circ} - 156^{\circ}$ C	at	25	mm.
2 brom para-tolyl benzoate			m.p.	74° - 7 5° C			
3 brom para-tolyl benzoate			m •p•	6 8.5[°] - 69 [°] C			
3,5 di-brom para-tolyl bens	zoat	Э	m.p.	89° - 90° C			

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BIBLIOGRAPHY.

* * * *

1.	I.D.Vorländer Ber. der Deut	. Chem. Gesell.	52B	263	(1919)
2.	James Kendall	J.A.C.S.	38	1309	(1916)
		J.A.C.S.	36	1 7 22	(1914)
3.	0. Maass & D. McIntosh	J.A.C.S.	34	1284	(1912)
		J.A.C.S.	33	7 0	(1911)
4.	D. McIntosh	J.A.C.S.	32	542	(1910)
5.	James Kendall & Carpenter	J.A.C.S.	36	2498	(1914)
6.	Schotten-Baumann Reaction:Di	e Methoden der Organ	ischen	Chemi	e:Weyl.
		Pages 57	2,580,	748,84	6,1278.
7.	Werner Kelbe	В.	<u>19</u>	92	
8.	Rav & Lal Dev	J.C.S.	11 7	1405	(1920)