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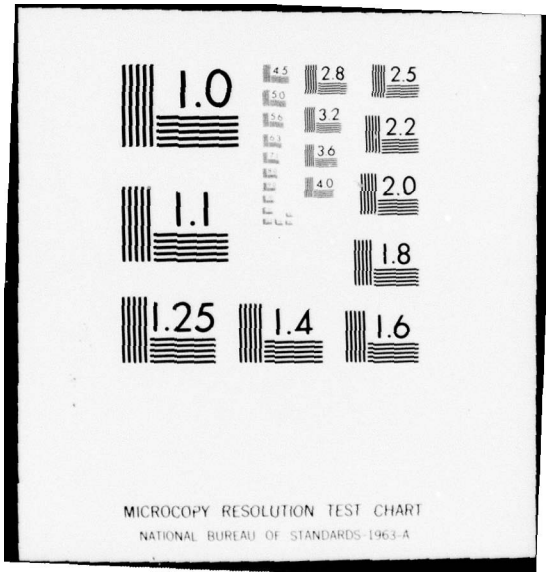
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SYNTHESIS OF BISBENZIL ISOMERS AND DERIVATIVES

Final Report

10 January 1975 to 10 January 1976

February 1976

Kay L. Paciorek
Thomas I. Ito
Reinhold H. Kratzer

Prepared Under Contract N00024-75-C-5061

For

NAVAL SEA SYSTEMS COMMAND
Code SEA-0352
Department of the Navy
Washington, D. C. 20362

By

Ultrasystems, Inc.
Chemicals and Materials Research Department
2400 Michelson Drive
Irvine, California 92664

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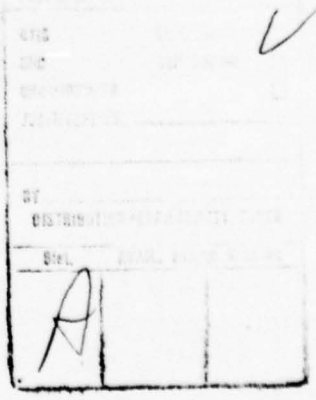


FOREWORD

This Final Report describes the work performed by the Chemicals and Materials Research Department, Ultrasystems, Inc. during the period from 10 January 1975 to 10 January 1976 under Contract N00024-75-C-5061. The investigations were carried out by K. L. Paciorek, T. I. Ito, and R. H. Kratzer, Program Manager. This contract was administered by Naval Sea Systems Command, Code SEA-0352, with M. Kinna as the Project Manager.

1. ABSTRACT AND SUMMARY

The goal of this investigation was to apply the modified benzoin condensation, used successfully in the synthesis of unsubstituted para-bis(phenylglyoxyloyl)benzene, to the preparation of substituted para-derivatives as well as to the production of selected meta and ortho isomers.

Using this process the substituted compounds: p-bis(p-methoxyphenylglyoxyloyl)benzene, p-bis(p-hydroxyphenylglyoxyloyl) benzene, and p-bis(p-chlorophenylglyoxyloyl)benzene, were obtained in yields of 41, 16, and 46%, respectively. The formation of the bis-cyanohydrin intermediate was unequivocally proven by its transformation to the para-bis-hydroxy acid.

The extension of the modified benzoin reaction to the synthesis of meta and ortho isomers of p-bis(phenylglyoxyloyl)benzene was to date unsuccessful. In the case of isophthalaldehyde the intermediate bis-cyanohydrin was unexpectedly stable, which under the conditions employed prevented its condensation with benzaldehyde. This material was characterized by the hydrolysis to the meta-bis(hydroxy acid). Reaction of benzaldehyde cyanohydrin with isophthalaldehyde resulted in hydrogen cyanide exchange and formation of the bis-cyanohydrin of isophthalaldehyde and benzaldehyde. The cyanohydrin derived from phthalaldehyde appeared to undergo self-condensation above $0^{\circ}C$; at lower temperatures no reaction with benzaldehyde occurred.

2. INTRODUCTION AND RATIONALE

Previous investigations of polyphenylquinoxalines, principally the polymer derived from the condensation of diaminobenzidine with p-bis(phenylglyoxyloyl) benzene, have shown these materials to exhibit a number of potential advantages for application in many advanced DOD systems. In addition to good flame resistance, excellent thermal stability, and good film and fiber forming characteristics this polymer, when reinforced with carbon fibers, provides excellent ablatives for advanced missile thermal protection and potential high temperature structural materials of reduced weight. The high impact resistance and the pronounced capability for shock attenuation furthermore make this polymer very attractive for those applications where these properties become important to survival, e.g., in nuclear encounters. These latter properties result from a low thermo-mechanical coupling coefficient (Gruneisen parameter) and an enormously high strain energy to failure as shown in Hopkinson bar experiments.

Polyphenylquinoxalines are currently being investigated at the Army Materials and Mechanics Research Center to develop flame resistant protective clothing and by the Aerospace Corporation for the Navy and the Defense Nuclear Agency to produce items and components for applications where nuclear hardness is a prime objective. Other studies are directed at utilizing polyphenylquinoxalines in high strength-low weight system components, in energy absorbing (energy managing) structures, as stable and well adhering protective coatings, and as stable, non-corrosive adhesives.

To most effectively exploit polyphenylquinoxaline (PPQ) technology it was first necessary to find a simple, low cost synthesis route to the preparation of p-bis(phenylglyoxyloyl)benzene since this compound was by far the most expensive of the two comonomers needed for the preparation

of the base polymer and for all practical purposes economically not feasible even for high pay-off applications.

Thus, in the preceding program [1] a process for the economical synthesis of p-bis(phenylglyoxyloyl)benzene was developed. It was shown that bis-aldehydes, as represented by terephthalaldehyde can undergo a modified benzoin condensation with monoaldehydes, e.g., benzaldehyde, provided the two aldehyde functions present on the phenylene group are suitably derivatized. The specific compound used was the terephthalaldehyde bis-bisulfite adduct and via this intermediate a bis-benzoin was obtained which was then readily oxidized to p-bis(phenylglyoxyloyl)benzene.

The second requirement was to provide a selection of bis(glyoxyloyl)benzene monomers in order to allow tailoring of polymer properties, to improve handling and processing characteristics of the resin, and in general to produce the monomers needed for the preparation of materials of larger property ranges for current and envisioned applications. Utilizing p-bis(phenylglyoxyloyl)benzene isomers and suitably substituted derivatives is expected to lead to polymer systems which offer alternate routes for chain extension, which are capable of forming readily processible prepolymers, or which contain crosslinking sites so that mechanical properties, char yields or e.g., degradation products, could be varied and controlled as desired.

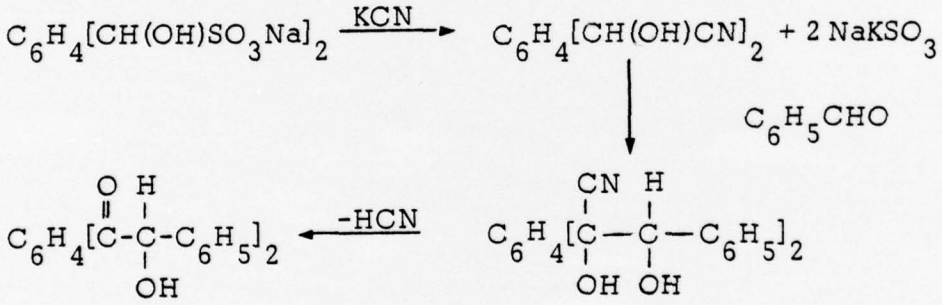
Consequently the logical approach taken in this second phase was to determine how applicable the modified benzoin condensation is to the preparation of other bis-glyoxyloyl comonomers, both isomers and substituted derivatives of p-bis(phenylglyoxyloyl)benzene.

3. RESULTS AND DISCUSSION

The objective of this program was to determine the applicability of the modified benzoin condensation to the synthesis of substituted p-bis(phenylglyoxyloyl)benzenes and its extension to the formation of the meta and ortho isomers. For clarity of presentation the technical discussion will be divided accordingly.

3.1 p-Bis(phenylglyoxyloyl)benzenes

Based on the work performed to date it is believed that the sequence given below illustrates the modified benzoin condensation:



Under the past contract[1] what appeared to be the bis-cyanohydrin was isolated, however at that time it was characterized only by infrared spectral analysis. It has been now established by hydrolyzing the cyanohydrin to the α-hydroxy acid, i.e.,

$$C_6H_4[CH(OH)CN]_2 \xrightarrow[HCl]{H_2O} C_6H_4[CH(OH)COOH]_2$$

that the cyanohydrin is indeed formed. The acid did not have an observable melting point,[2] however its DSC curve (Figure 1) exhibited an endotherm at about 220°C. The latter was found to correspond to lactide formation

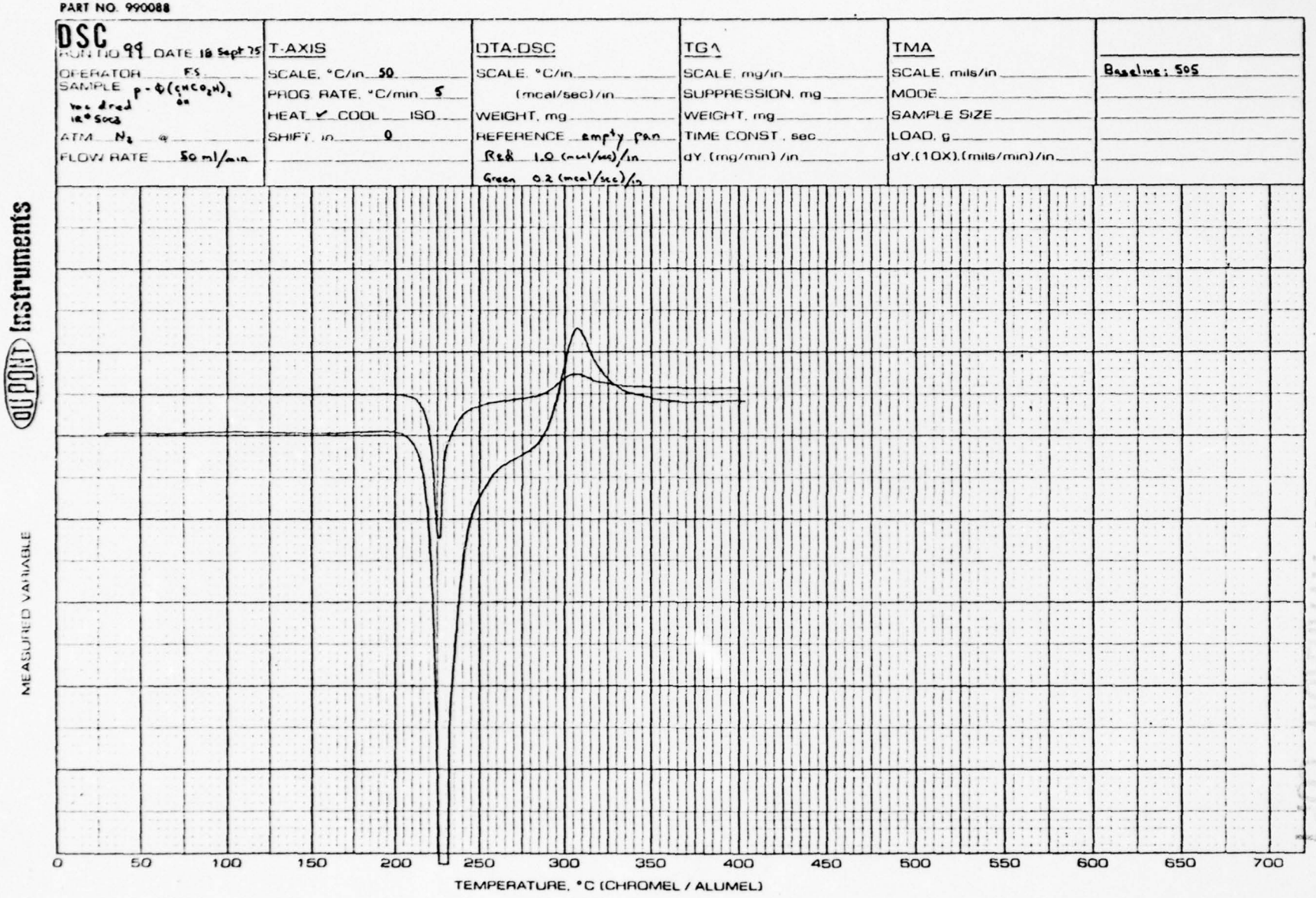
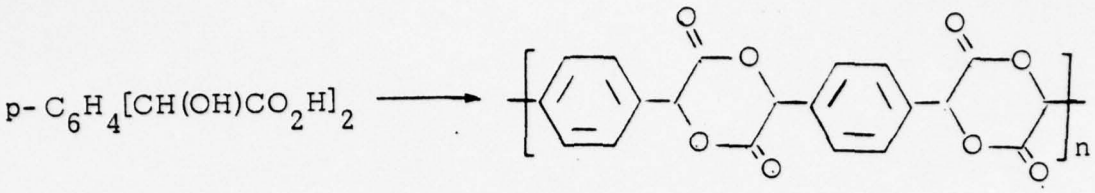


Figure 1 : DSC of p-$C_6H_4[CH(OH)COOH]_2$



as shown by the thermogravimetric analysis weight loss of 12.7% (see Figure 2) in reasonably good agreement with the theoretical value of 15.9% calculated for the above process.

By using the bis-cyanohydrin in the condensation reaction it is predetermined that the monoaldehyde must act as a hydrogen acceptor. Based on the data given in the literature [3] the 4-methoxybenzaldehyde in its condensation with benzaldehyde is the hydrogen donor. Thus one would expect 4-methoxybenzaldehyde to react less readily with the in situ formed bis-cyanohydrin than benzaldehyde. The experimental findings confirmed this prediction since the preparation of the p-methoxy-p-bisbenzoin required more vigorous conditions, i.e., longer reaction periods and a higher reaction temperature than the synthesis of the unsubstituted analogue. Unlike the parent unsubstituted p-bisbenzoin, the methoxy substituted material did not solidify from the reaction mixture upon cooling. Therefore, isolation of the crude substituted p-bisbenzoin was effected by distillation of excess p-methoxybenzaldehyde. The pure p-methoxy-p-bisbenzoin was obtained by crystallization from ethanol. Oxidation of the crude residue using the ammonium nitrate-cupric acetate-acetic acid system gave the substituted bisbenzil in an overall yield of 40.5%. Treatment of the p-bis(p-methoxyphenylglyoxyloyl)benzene with aqueous hydrobromic acid-glacial acetic acid [4-6] gave the p-bis(p-hydroxyphenylglyoxyloyl)benzene in an overall yield of 16%. The reaction scheme is given below.

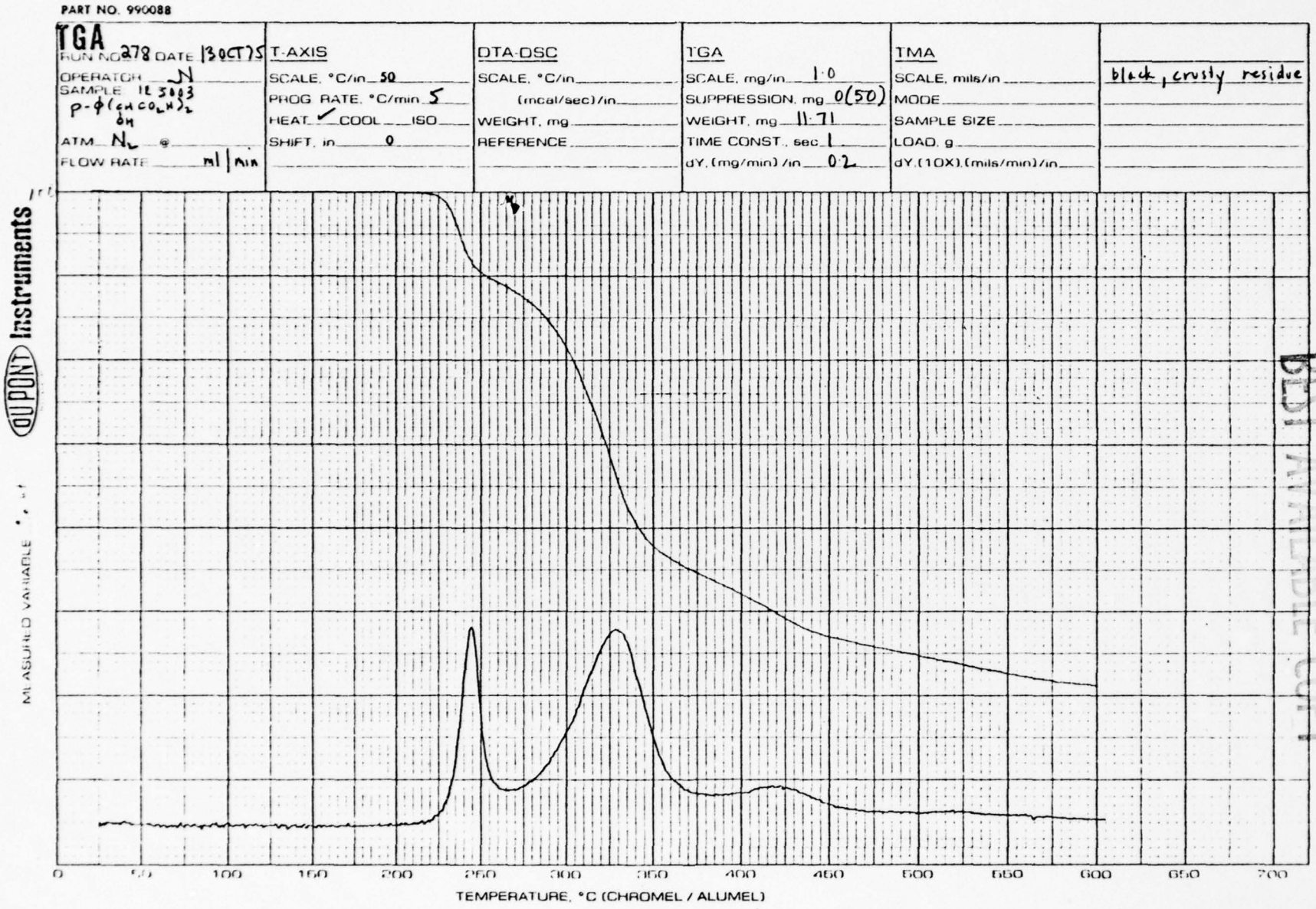
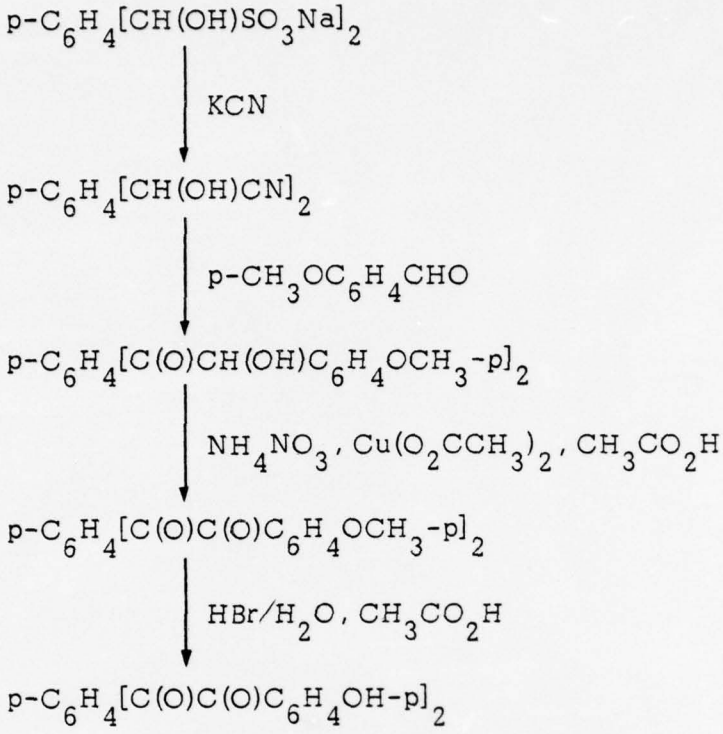


Figure 2: TGA of p-$C_6H_4[CH(OH)COOH]_2$



Inasmuch as p,p'-dimethoxybenzoin and p,p'-dimethoxybenzil are potential by-products in the synthesis of the bis-analogues, both of these compounds were prepared for comparison purposes using literature procedures.[7]

The addition of the in situ prepared terephthalaldehyde bis-cyanohydrin to p-chlorobenzaldehyde followed by oxidation gave the p-bis(p-chlorophenylglyoxyloyl)benzene in 46% yield. The intermediate bisbenzoin was purified by crystallization from ether-petroleum ether mixture. For comparison purposes both the p,p'-dichlorobenzoin[8] and the p,p'-dichlorobenzil[9] were prepared.

Both the methoxy and chloro moieties are nucleophilic in nature. Thus it was of interest to determine whether the modified condensation will also occur with an electrophilic substituent. The specific compound

chosen was nitrobenzaldehyde. No desired product was isolated, the failure of this reaction could very well be due to the electron withdrawing action of the nitro group resulting in the deactivation of the carbonyl function as hydrogen-acceptor.[10] It should be noted that p-nitrobenzaldehyde itself does not undergo the benzoin condensation.[3]

In view of the successful preparation of the methoxy- and chloro-substituted bisbenzoins it can be concluded that the modified benzoin condensation, at least insofar as the para isomers are concerned, offers a general type of a method and is not limited to the parent compound.

3.2 m-Bis(phenylglyoxyloyl)benzene

Attempts to prepare m-bisbenzoin via the conventional benzoin condensation using isophthalaldehyde and benzaldehyde in the presence of potassium cyanide failed to yield the desired product; rather what appeared to be telomers of isophthalaldehyde derived benzoins and other unidentified condensation species were produced in analogy with the studies using terephthalaldehyde. Employing benzoin instead of benzaldehyde in the condensation process with isophthalaldehyde failed to give the desired conproportionation:[3]

$$C_6H_5C(O)CH(OH)C_6H_5 + 1,3\text{-}C_6H_4(CHO)_2 \xrightarrow{\not\ KCN} 1,3\text{-}C_6H_4[C(O)CH(OH)C_6H_5]_2$$

Accordingly, the modified benzoin condensation approach was tried next. Unlike the preparation of the bis-bisulfite adduct of terephthalaldehyde, the sodium bisulfite adduct of isophthalaldehyde did not precipitate from the aqueous solution upon the addition of isophthal-

aldehyde to the sodium bisulfite solution. However, modification of the solvent medium,[11] by the addition of alcohol to the sodium bisulfite solution, did result in the precipitation and isolation of the adduct in quantitative yield.

The reaction of the in situ generated isophthalaldehyde bis-cyanohydrin with benzaldehyde followed by distillation of the excess benzaldehyde and residue oxidation did not afford any products resembling the sought m-bisbenzil. A series of reactions were conducted varying the solvent and addition mode. These are summarized in Table I and essentially follow the procedures found optimal for the synthesis of the p-bisbenzoin. Determination as to whether the desired m-bisbenzoin had been formed was made by oxidation of the "condensation product" followed by attempts to isolate the desired m-bisbenzil. Under none of the conditions tested was m-bisbenzoin apparently formed, based on the lack of detecting any m-bisbenzil on oxidation of the residue obtained upon the removal of benzaldehyde and other volatiles. In the absence of ethanol, only traces of benzoin appeared to have been produced. However, conducting the process in the presence of ethanol resulted in a 50-68% yield of benzoin. The formation of benzoin could be explained by the following sequence:

$$m\text{-}C_6H_4[CH(OH)CN]_2 + 2\,C_6H_5CHO \rightleftharpoons m\text{-}C_6H_4(CHO)_2 + 2\,C_6H_5CH(OH)CN$$

$$C_6H_5CH(OH)CN + C_6H_5CHO \longrightarrow C_6H_5CH(OH)C(O)C_6H_5 + HCN$$

In accordance with the above scheme, for every mole of isophthalaldehyde bis-cyanohydrin employed two moles of benzoin should be formed. Yet it was found that in the absence of ethanol (see page 16) the reaction occurs predominantly in the direction of the bis-cyanohydrin. It would thus seem that one is dealing here with a rather complex mechanism, not the oversimplified sequence given above.

TABLE I

REACTIONS OF IN SITU PREPARED

m-$C_6H_4[CH(OH)CN]_2$ WITH C_6H_5CHO[a]

Run No.	Bisulfite		C_6H_5CHO		Solvent[b]	Time	Temp	Remarks
	g	mmol	g	mmol		hr	°C	
31-58	2.00	5.86	3.75	35.33	None	4.0	76	Isolated from organic layer solid, 0.39 mg, mp 118-139°C; oxidation failed to yield m-bisbenzil
34-62	2.00	5.86	3.64	34.35	None	5.0	81-85	After distillation of the excess C_6H_5CHO, 1.39 g residue was obtained; oxidation gave oil (0.88 g)
39-69	3.02	8.81	5.73	53.98	None	5.5	72-76	After distillation of the excess C_6H_5CHO, 2.87 g residue was obtained; contained some $C_6H_5CH(OH)COC_6H_5$; oxidation failed to yield m-bisbenzil.
41-73	2.00	5.88	3.75	35.33	C_2H_5OH/H_2O	5.5	94-107	To the bisulfite of $C_6H_4(CHO)_2$ in 50% ethanol was added KCN in H_2O; this was then added into C_6H_5CHO; 66% yield of benzoin was realized.
43-76	2.00	5.88	3.75	35.33	C_2H_5OH/H_2O	5.0	74-86	The in situ prepared biscyanohydrin was added to C_6H_5CHO in ethanol (5 ml); 68% yield of benzoin was realized.
44-78	2.00	5.88	3.75	35.33	C_2H_5OH/H_2O	4.8	88-75	To the in situ prepared biscyanohydrin was added at 0°C C_6H_5CHO in C_2H_5OH followed initially by stirring at 0°C for 1 hr. In this experiment a 50% yield of benzoin was obtained.

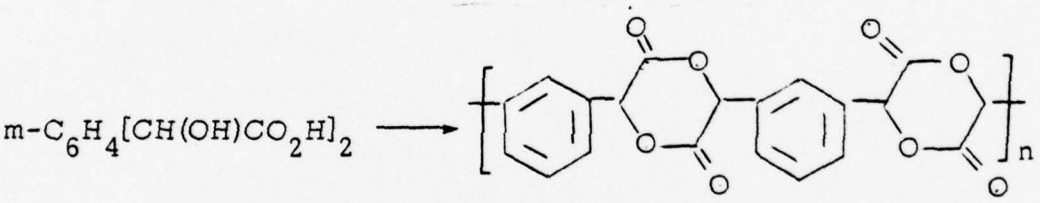
a) The isophthalaldehyde biscyanohydrin, $C_6H_4[CH(OH)CN]_2$, was prepared in situ by addition of 2 moles of cold potassium cyanide solution to an aqueous solution of the bisulfite addition compound cooled in 0°C bath. In the first three runs this solution was added to hot benzaldehyde. In experiment 41-73 the bisulfite was dissolved in aqueous ethanol and then was treated with potassium cyanide solution. In experiment 43-76 the preformed biscyanohydrin was added to ethanol-benzaldehyde solution, whereas reverse addition was employed in the last experiment.

b) Where no solvent is indicated it means that no solvent other than water, in which the cyanohydrin was formed, was employed.

Infrared spectral analysis of the material isolated from the interaction of potassium cyanide with the bisulfite adduct of isophthalaldehyde, showed that the m-bis-cyanohydrin was formed. This was confirmed by hydrolysis of the cyanohydrin to the α-hydroxy acid

$$m\text{-}C_6H_4[CH(OH)CN]_2 \xrightarrow[HCl]{H_2O} m\text{-}C_6H_4[CH(OH)COOH]_2$$

The DSC curve of the acid (Figure 3) exhibited one endotherm at 157°C, corresponding to the observed melting point, and a second endotherm at about 220°C. As in the case of the para isomer the latter endotherm is most likely due to lactide formation since the weight loss calculated from the TGA (Figure 4) was 11.3% (theory 15.9%):



It should be noted that the isophthalaldehyde bis-cyanohydrin appeared to be surprisingly thermally stable. Interaction of the isophthalaldehyde bis-cyanohydrin with benzaldehyde at 90°C in the absence of solvent resulted in the recovery of starting material. Performing a parallel reaction in the presence of an acid acceptor, triethylamine, with or without ethanol as co-solvent, gave a product which on oxidation formed what appeared to be aromatic acids and/or aldehydes (see Table II).

In view of the failure to effect the desired condensation utilizing the isophthalaldehyde bis-cyanohydrin/benzaldehyde system, attention was directed toward the reversed functionality, i.e., isophthalaldehyde and benzaldehyde cyanohydrin (mandelonitrile). The interaction of equivalent quantities of in situ prepared mandelonitrile with isophthalaldehyde resulted

Figure 3: DSC of m-$C_6H_4[CH(OH)COOH]_2$

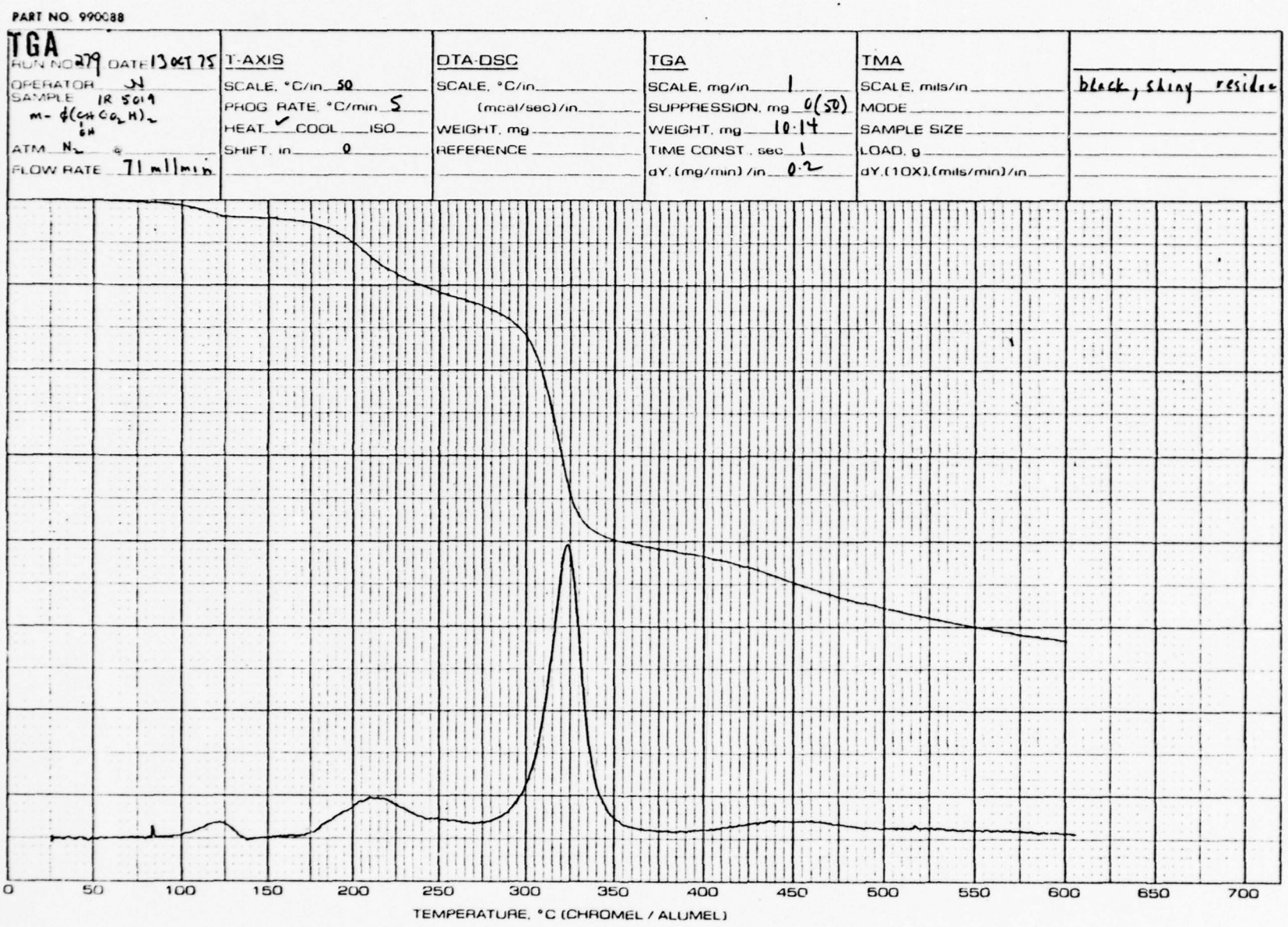


Figure 4: TGA of m-$C_6H_4[CH(OH)COOH]_2$

TABLE II

REACTIONS OF ISOLATED ISOPHTHALALDEHYDE BISCYANOHYDRIN WITH BENZALDEHYDE

Run No.	Biscyanohydrin		Benzaldehyde		Solvent	Time	Temp	Remarks
	g	mmol	g	mmol		hr	°C	
38-68	0.51	2.73	1.87	17.67	None	7.25	68-78	0.50 g isophthalaldehyde biscyanohydrin recovered after distillation of the excess C_6H_5CHO
42-74	0.25	1.33	1.04	9.81	C_2H_5OH	18 8	RT 86-91	Triethylamine used as catalyst; oxidation of residue after distillation of the excess C_6H_5CHO yielded product with carboxyl groups
5-75-14	1.61	8.6	1.88	17.7	None	5.25	52-57	Triethylamine used as catalyst; obtained 1.20 g of ether insoluble material (not m-bisbenzoin by IR); 1.64 g triethylamine-free, ether soluble material; distillation gave 0.44 g C_6H_5CHO and 0.71 g residue which on oxidation yielded 14 mg of an inorganic compound and an oil which exhibited carboxyl group in its IR spectrum.

in almost quantitative yields of benzaldehyde, some isophthalaldehyde bis-cyanohydrin and the formation of what appears to be condensation products of the isophthalaldehyde bis-cyanohydrin:

$$2\,C_6H_5CH(OH)CN + 1,3\text{-}C_6H_4(CHO)_2$$

$$\downarrow$$

$$2\,C_6H_5CHO + 1,3\text{-}C_6H_4[CH(OH)CN]_2 + \text{condensation products}$$

Conducting an equivalent reaction but employing the isolated mandelonitrile together with isophthalaldehyde (in the absence of solvent and the inorganic salts) resulted in a quantitative exchange, i.e.,

$$2\,C_6H_5CH(OH)CN + m\text{-}C_6H_4(CHO)_2 \longrightarrow 2\,C_6H_5CHO + m\text{-}C_6H_4[CH(OH)CN]_2$$

This series of reactions is summarized in Table III.

The results obtained tend to indicate that in the processes involving benzaldehyde or its cyanohydrin the preferential formation and the stability of the isophthalaldehyde bis-cyanohydrin prevents the condensation from occurring. It could not be ignored that utilization of a different aldehyde could provide a driving force for this reaction to take place. Thus the in situ generated isophthalaldehyde bis-cyanohydrin was reacted with p-nitrobenzaldehyde and p-chlorobenzaldehyde. With the former aldehyde no substance which could be identified as the bis-benzoin was isolated. Oxidation of the intermediate obtained from the p-chlorobenzaldehyde reaction resulted in the isolation of trace amounts of p,p'-dichlorobenzil but none of the desired m-bis(p-chlorophenylglyoxyloyl) benzene was detected.

The failure to date of the modified benzoin reaction to lead to benzoin condensation of the isophthalaldehyde does not necessarily mean that this process could not be induced to occur provided the right conditions are found.

TABLE III

REACTIONS OF BENZALDEHYDE CYANOHYDRIN (MANDELONITRILE) WITH ISOPHTHALALDEHYDE

Run No.	C_6H_5-CH(OH)SO_3Na		m-$C_6H_4(CHO)_2$		Solvent	Time	Temp °C	Remarks
	g	mmol	g	mmol				
47-83	n.a.		0.99	7.40	C_2H_5OH/H_2O	7	80-103	Commercial mandelonitrile[a] used; no solid formed on cooling or precipitation into H_2O
50-86[b]	2.00	9.52	0.63	4.72	C_6H_6/H_2O	2	61-80	Isolated solid, 0.68 g, mp > 285°C; from C_6H_6 layer, C_6H_5CHO was obtained (0.95 g)
52-89[b]	2.06	9.80	0.65	4.88	C_6H_6/H_2O	5.5	75-92	Isolated were C_6H_5CHO and 0.59 g of solid similar to that obtained in Run 50-86
53-92[c]	4.54	21.59	0.50	3.72	C_6H_6	14	74-102	Isolated C_6H_5CHO only
5-75-9[c]	1.70	8.07	0.47	3.49	Neat	10.5	90-105	Obtained following distillation: 0.47 g C_6H_5CHO, 0.13 g m-$C_6H_4(CHO)_2$; 0.74 g of m-$C_6H_4[CH(OH)CN]_2$ as involatile residue

a Mandelonitrile was purchased from Aldrich Chemical Company. b In situ prepared mandelonitrile.

c Mandelonitrile isolated.

The point well worth stressing is that the bis-cyanohydrin has been produced and it is believed that this compound can be made susceptible to undergo the desired condensation in a solvent medium of appropriate polarity, ionization strength, and ion concentration.

3.3 o-Bis(phenylglyoxyloyl)benzene

The synthesis of o-bis(phenylglyoxyloyl)benzene was not extensively investigated. The phthalaldehyde bis-bisulfite adduct was prepared in 87% yield according to the procedure used in the preparation of the meta isomer. Reaction of the phthalaldehyde bis-bisulfite adduct with potassium cyanide failed to result in the isolation of the phthalaldehyde bis-cyanohydrin due to what appears to be its extreme instability at temperatures above $0^{\circ}C$. Initial studies of the modified benzoin condensation using the phthalaldehyde bis-bisulfite adduct tend to indicate that the phthalaldehyde bis-cyanohydrin initially formed undergoes some type of self-condensation. Based on this result, lower temperatures and solvent mixtures were utilized in the subsequent studies. The experiments conducted are summarized in Table IV. These data tend to indicate that the extent of self-condensation is reduced at lower temperatures but that the use of ethanol as co-solvent did not seem to have any effect on the condensation reaction. In none of the reactions was the desired o-bis-benzoin produced. Here also the proof whether the desired bis-benzoin intermediate was formed was based upon the isolation of the respective bisbenzil from the oxidation of the residue remaining after removal of excess benzaldehyde and other volatiles.

In view of the limited study performed with phthalaldehyde it is difficult to arrive at any meaningful conclusions regarding the ultimate feasibility of this process. It is obvious, however, that the phthalaldehyde cyanohydrin, if formed at all, (its presence has not been established) is exceedingly unstable. If one compares the three isomeric

systems it is tempting to speculate that the successful condensation carried out in the case of the para-compound is due to the "right" reactivity of the terephthalaldehyde cyanohydrin. In the case of the meta isomer the cyanohydrin is apparently too stable or internally stabilized to undergo the desired condensation. In the ortho system reactivity leading to self-condensation predominates, most likely due to steric effects inasmuch as the electronic factors should be comparable to those prevalent in the p-analogue.

3.4 Summary and Conclusion

To summarize, the previously developed modified benzoin condensation was successfully extended to the preparation of p-substituted 1,4-bis(phenylglyoxyloyl)benzenes such as the p-chloro-, p-methoxy-, and p-hydroxy-materials. Although to date the process was not successful in synthesizing 1,3-bis(phenylglyoxyloyl)benzenes a potentially useful precursor for comonomers, 1,3-bis-cyanohydrin benzene, was obtained and its identity established by conversion to the corresponding bis-hydroxy acid. This compound in itself provides an important monomer precursor of the meta-glyoxyloyl-benzene system.

TABLE IV

REACTIONS OF IN SITU PREPARED o-$C_6H_4[CH(OH)CN]_2$

WITH C_6H_5CHO[a]

Run No.	Bisulfite		C_6H_4CHO		Solvent[b]	Time	Temp	Remarks
	g	mmol	g	mmol		hr	°C	
57-97	3.01	8.79	5.73	53.98	None	3.9	65-79	After distillation of the excess C_6H_5CHO 1.50 g residue obtained; oxidation gave 6.1 mg, solid, mp > 165°C and red oil
60-101	2.04	5.96	3.12	29.44	None	4.1	87-92	$C_6H_5CH(OH)COC_6H_5$ (0.16 g) isolated plus red oil (0.56 g)
62-104	2.01	5.86	11.87	111.86	None	1 15.1	0 50-60	After distillation of the excess C_6H_5CHO 1.44 g residue obtained; oxidation yielded solid (80 mg, inorganic), mp > 275°C and red oil
64-108	2.00	5.85	11.87	111.66	None	1.1 1.2	-1-0 54-60	After distillation of the excess C_6H_5CHO 1.46 g red oil residue was obtained
68-115	2.00	5.85	11.87	111.86	C_2H_5OH/H_2O	2 1.5	-16- -6 51-71	After distillation of the excess C_6H_5CHO 1.0 g residue was obtained, oxidation yielded solid (26 mg, inorganic) mp > 200°C and red oil
78-128	2.00	5.85	11.87	111.86	C_2H_5OH/H_2O	2 2 0.5	-10- -4 0-5 27	After distillation of the excess C_6H_5CHO 1.47 g residue was obtained, oxidation yielded solid (59 mg, inorganic) mp > 200°C and red oil

a) The phthalaldehyde cyanohydrin, $C_6H_4[CH(OH)CN]_2$, was prepared in situ by addition of 2 moles of cold potassium cyanide solution to a cooled aqueous solution of the bisulfite addition compound. The cyanohydrin solution was added to the benzaldehyde at the following rates: Run 57-97, 8 min; Run 60-101, 3 min; Runs 62-104, 64-108, 68-115, and 78-128, 2 sec.

b) Where no solvent is indicated it means that no solvent, other than water in which the cyanohydrin was formed, was used.

4. EXPERIMENTAL

All chemicals and solvents were employed for reaction as received. The reported melting points are uncorrected. Infrared spectra were recorded as Kel-F/Nujol double mulls with a Perkin-Elmer 21 Infrared Spectrophotometer, molecular weights were determined with the aid of a Mechrolab Vapor Pressure Osmometer Model 302, while the differential scanning calorimetry (DSC) spectra and the thermogravimetric analysis (TGA) traces were obtained with a DuPont 990/951 Thermal Analyzer. The elemental analyses were performed by Schwarzkopf Microanalytical Laboratory, Woodside, New York.

4.1 Preparation of 4,4'-Dimethoxybenzoin (Anisoin)

$$2\,p\text{-}CH_3OC_6H_4CHO \xrightarrow{KCN} p\text{-}CH_3OC_6H_4C(O)CH(OH)C_6H_4OCH_3\text{-}p$$

A solution of p-methoxybenzaldehyde (5.26 g, 38.6 mmol), potassium cyanide (0.54 g, 8.3 mmol), water (7.5 ml) and ethanol (7.5 ml) was heated with stirring at 83-105°C for 5 hr. Subsequently, additional potassium cyanide (0.52 g, 8.3 mmol) was added and the solution was refluxed (117-125°C) for further 6.7 hr. The two layers that formed upon cooling were separated. The organic layer solidified upon cooling in the refrigerator. The solid was washed with ether (10 ml) to yield a light yellow powder (1.65 g, 31.4% yield, mp 103-107°C). Recrystallization from aqueous alcohol afforded light yellow needles of anisoin, mp 108.5-110°C (lit.[7] 113°C).

4.2 Preparation of 4,4'-Dimethoxybenzil (Anisil)

$$p\text{-}CH_3OC_6H_4C(O)CH(OH)C_6H_4OCH_3\text{-}p \xrightarrow{[O]} p\text{-}CH_3OC_6H_4C(O)C(O)C_6H_4OCH_3\text{-}p$$

A solution of anisoin (1.04 g, 3.8 mmol), ammonium nitrate (1.01 g, 12.7 mmol) and cupric acetate (0.02 g, 0.1 mmol) in 80% acetic acid (20 ml) was heated at 104-114°C with stirring for 2.5 hr. Upon cooling, a precipitate was formed, it was filtered, and washed with water,

systems it is tempting to speculate that the successful condensation carried out in the case of the para-compound is due to the "right" reactivity of the terephthalaldehyde cyanohydrin. In the case of the meta isomer the cyanohydrin is apparently too stable or internally stabilized to undergo the desired condensation. In the ortho system reactivity leading to self-condensation predominates, most likely due to steric effects inasmuch as the electronic factors should be comparable to those prevalent in the p-analogue.

3.4 Summary and Conclusion

To summarize, the previously developed modified benzoin condensation was successfully extended to the preparation of p-substituted 1,4-bis(phenylglyoxyloyl)benzenes such as the p-chloro-, p-methoxy-, and p-hydroxy-materials. Although to date the process was not successful in synthesizing 1,3-bis(phenylglyoxyloyl)benzenes a potentially useful precursor for comonomers, 1,3-bis-cyanohydrin benzene, was obtained and its identity established by conversion to the corresponding bis-hydroxy acid. This compound in itself provides an important monomer precursor of the meta-glyoxyloyl-benzene system.

4. EXPERIMENTAL

All chemicals and solvents were employed for reaction as received. The reported melting points are uncorrected. Infrared spectra were recorded as Kel-F/Nujol double mulls with a Perkin-Elmer 21 Infrared Spectrophotometer, molecular weights were determined with the aid of a Mechrolab Vapor Pressure Osmometer Model 302, while the differential scanning calorimetry (DSC) spectra and the thermogravimetric analysis (TGA) traces were obtained with a DuPont 990/951 Thermal Analyzer. The elemental analyses were performed by Schwarzkopf Microanalytical Laboratory, Woodside, New York.

4.1 Preparation of 4,4'-Dimethoxybenzoin (Anisoin)

$$2\,p\text{-}CH_3OC_6H_4CHO \xrightarrow{KCN} p\text{-}CH_3OC_6H_4C(O)CH(OH)C_6H_4OCH_3\text{-}p$$

A solution of p-methoxybenzaldehyde (5.26 g, 38.6 mmol), potassium cyanide (0.54 g, 8.3 mmol), water (7.5 ml) and ethanol (7.5 ml) was heated with stirring at 83-105°C for 5 hr. Subsequently, additional potassium cyanide (0.52 g, 8.3 mmol) was added and the solution was refluxed (117-125°C) for further 6.7 hr. The two layers that formed upon cooling were separated. The organic layer solidified upon cooling in the refrigerator. The solid was washed with ether (10 ml) to yield a light yellow powder (1.65 g, 31.4% yield, mp 103-107°C). Recrystallization from aqueous alcohol afforded light yellow needles of anisoin, mp 108.5-110°C (lit.[7] 113°C).

4.2 Preparation of 4,4'-Dimethoxybenzil (Anisil)

$$p\text{-}CH_3OC_6H_4C(O)CH(OH)C_6H_4OCH_3\text{-}p \xrightarrow{[O]} p\text{-}CH_3OC_6H_4C(O)C(O)C_6H_4OCH_3\text{-}p$$

A solution of anisoin (1.04 g, 3.8 mmol), ammonium nitrate (1.01 g, 12.7 mmol) and cupric acetate (0.02 g, 0.1 mmol) in 80% acetic acid (20 ml) was heated at 104-114°C with stirring for 2.5 hr. Upon cooling, a precipitate was formed, it was filtered, and washed with water,

affording 0.47 g (45.1% yield) of fine yellow crystals (mp 132-132.5°C, lit.[4] 133°C).

4.3 Preparation of p-Bis(p-methoxyphenylglyoxyloyl)benzene

An aqueous solution (150 ml) of potassium cyanide (19.5 g, 0.3 mol) was added over a period of 13 min to a stirred and cooled (0°C) suspension of $p\text{-}C_6H_4[CH(OH)SO_3Na]_2$ (51.5 g, 0.15 mol) in water (150 ml). The aqueous solution of the thus prepared terephthalaldehyde bis-cyanohydrin was then added dropwise to heated (84-86°C) p-methoxybenzaldehyde (125.3 g, 0.92 mol) under an inert atmosphere over a period of 10 min. The resulting mixture was stirred and heated at 76-89°C for a total of 4.5 hr and subsequently kept in the refrigerator for eight days. The two layers that formed upon cooling were separated. The organic layer was washed with water (2 x 75 ml) and then distilled in vacuo to remove the excess p-methoxybenzaldehyde and residual water giving 70.3 g (115% yield) of crude p-methoxy-p-bisbenzoin. A portion of this material (28.4 g) was subsequently dissolved in 80% acetic acid (200 ml). To this solution was then added ammonium nitrate (28.5 g, 0.36 mol) and cupric acetate (0.5 g, 2.5 mmol). The resulting mixture was stirred and heated at reflux (110-111°C) for 4.5 hr. During the reflux period a yellowish solid precipitated. The cooled mixture was filtered and the solid washed with cold acetic acid and dried in air to give 10.33 g (42% yield based on the bisulfite adduct originally used). This material was treated with hot chloroform (200 ml) and filtered; evaporation of chloroform afforded (9.02 g, 40.5% yield based on the bisulfite adduct originally used), mp 210-212°C. Crystallizations from aqueous acetic acid followed by drying in vacuo (5 hr at 80°C) gave pure p-methoxy-p-bisbenzil, mp 216-218°C; IR 5.97, 6.05 (CO), 7.82 and 9.67μ (OCH_3): Anal. Calcd for $C_{24}H_{18}O_6$: C, 71.64; H, 4.51; MW, 402. Found: C, 71.55; H, 4.55, MW, 437.

4.4 p-Methoxy-p-bisbenzoin p-C_6H_4[C(O)CH(OH)$C_6H_4$$OCH_3$-p]$_2$

A portion (700 mg) of the crude p-methoxy-p-bisbenzoin described in Experiment 4.3 was washed with acetone giving 260 mg of insoluble material. This material was then dissolved in hot ethanol, treated with decolorizing carbon and filtered; on cooling crystals (91 mg, mp 213-217°C) were obtained. These were recrystallized again from hot ethanol affording crystals (65 mg): mp 217.5-219°C, IR: 2.95 (OH), 6.00 (CO), 7.87, 9.70 (OCH_3) and 10.25μ (band characteristic of benzoins). Anal. Calcd for $C_{24}H_{22}O_6$: C, 70.93; H, 5.46. Found: C, 70.69; H, 5.56.

4.5 Preparation of p-Bis(p-hydroxyphenylglyoxyloyl)benzene

$$p\text{-}C_6H_4[C(O)C(O)C_6H_4OCH_3\text{-}p]_2 \xrightarrow[CH_3CO_2H]{HBr/H_2O} p\text{-}C_6H_4[C(O)C(O)C_6H_4OH\text{-}p]_2$$

Following the procedure of Hergenrother[6] a mixture of p-methoxy-p-bisbenzil (2.52 g, 6.26 mmol), 48% aqueous hydrobromic acid (10.6 ml) and glacial acetic acid (25 ml) was refluxed for 68 hr. When the cooled dark colored solution was poured into an ice-water mixture (400 ml) a gray green solid formed which was filtered off and redissolved in 5% potassium hydroxide solution (10 ml). Undissolved material was removed by filtration. The filtrate was acidified with 6N hydrochloric acid to give a dark green solid which was filtered and dried (1.67 g, 70.6% yield). Purification was effected by dissolving the solid in hot ethanol, treating the resulting solution with decolorizing carbon then filtered into hot water (400 ml). The brown-orange solid that formed on cooling was filtered and dried to give 0.94 g (39.7% yield) of p-hydroxy-p-bisbenzil, mp 221-224°C. Crystallization from aqueous ethanol gave lemon yellow needles, mp 233-234°C; IR: 3.05, 7.45, 8.25 (aromatic OH) 5.98 and 8.00μ (aromatic CO). Anal. Calcd for $C_{22}H_{14}O_6$: C, 70.59; H, 3.77. Found: C, 70.03; H, 3.81.

4.6 Preparation of 4,4'-Dichlorobenzoin[8]

$$p\text{-}ClC_6H_4CHO \xrightarrow[aq\ CH_3OH]{KCN} p\text{-}ClC_6H_4CH(OH)C(O)C_6H_4Cl\text{-}p$$

An aqueous solution (2 ml) of potassium cyanide (0.52 g, 7.99 mmol) was added dropwise to a refluxing methanolic solution (5 ml) of p-chlorobenzaldehyde (4.06 g, 28.88 mmol) under an inert atmosphere. The resulting solution was refluxed for 30 min then cooled. The solvents were removed in vacuo, the residue taken up in benzene (40 ml) and washed with water (3 x 10 ml) , 20% sodium bisulfite (8x10 ml) and water (4 x 20 ml),then dried over anhydrous magnesium sulfate. The yellow oil (3.79 g) obtained on removal of solvent exhibited in its IR: 2.93 and 10.23 (OH), 5.94 (CO), and 9.12μ (aromatic halide).

4.7 Preparation of 4,4'-Dichlorobenzil

$$p\text{-}ClC_6H_4CH(OH)C(O)C_6H_4Cl\text{-}p \xrightarrow{[O]} p\text{-}ClC_6H_4C(O)C(O)C_6H_4Cl\text{-}p$$

The oil (3.79 g) obtained in Experiment 4.6 was dissolved in 80% acetic acid. To this solution were added ammonium nitrate (3.78 g, 47.22 mmol) and cupric acetate (60 mg). The mixture was stirred and heated (72-104°C) for 1.25 hr, then cooled, giving yellow needles of 4,4'-dichlorobenzil, mp 190-193°C (lit.[9] 195-196°C); IR: 6.00 and 8.21 (aromatic CO) and 9.10μ (aromatic halide).

4.8 Preparation of p-Chloro-p-bisbenzoin

A cold aqueous solution (25 ml) of terephthalaldehyde bis-cyanohydrin prepared from terephthalaldehyde bis-bisulfite adduct (4.16 g, 12.2 mmol) and potassium cyanide (1.60 g, 24.6 mmol) was added dropwise to heated (75°C) p-chlorobenzaldehyde (3.59 g, 25.5 mmol) under an inert atmosphere over a period of 10 min. The resulting mixture was stirred and heated (65-72°C) for 3.5 hr, cooled, and placed into the refrigerator for 1.5 hr. The aqueous layer was decanted and the organic material washed with water until the aqueous washings were

fairly colorless. The material was then treated with ether (7 x 10 ml) to give an orange solution and 0.89 g of solid. Removal of the solvent afforded 4.06 g of an oil whose IR was identical with that of the ether insoluble material; bringing the yield of crude benzoin to 97%. Purification of 0.21 g of the oil from an ether-petroleum ether (60-110°C) mixture afforded 60 mg of p-chloro-p-bisbenzoin; mp 107-108.5°C; IR: 2.95, 10.20 (OH), 5.95 (CO) and 9.10μ (aromatic halide). Anal. Calcd for $C_{25}H_{16}Cl_2O_4$: C, 63.63; H, 3.88; Cl, 17.08. Found: C, 63.32, H, 4.03; Cl, 17.00.

4.9 Preparation of p-Bis(p-chlorophenylglyoxyloyl)benzene

Ether soluble material (2.33 g) from the preparation of p-chloro-p-bisbenzoin (see Experiment 4.8) was dissolved in 80% acetic acid (10 ml). Ammonium nitrate (2.34 g, 29.2 mmol) and cupric acetate (0.04 g) were added and the mixture was heated (102-115°C) for 1.5 hr during which time the initially orange solution turned green. After cooling the yellow precipitate which formed was filtered, washed with cold acetic acid (20 ml) and water (80 ml) then dried to give 1.13 g, (47% yield) of crude p-chloro-p-bisbenzil (mp 257-263°C). To effect purification the material was dissolved in chloroform and filtered. Removal of solvent produced a yellow-brown solid (0.67 g) which on recrystallization from acetic acid gave pure p-chloro-p-bisbenzil, mp 271.5-272.5; IR: 5.95, 8.18 (aromatic CO) and 9.02μ (aromatic halide). Anal. Calcd for $C_{22}H_{12}Cl_2O_4$: C, 64.26: H, 2.94; Cl, 17.24. Found: C, 64.56; H, 3.01: Cl, 17.28.

4.10 Attempted Preparation of p-Nitro-p-bisbenzoin

A cold aqueous solution (10 ml) of terephthalaldehyde bis-cyanohydrin prepared from terephthalaldehyde bisbisulfite adduct (2.00 g, 5.84 mmol) and potassium cyanide (0.76 g, 11.68 mmol) was added dropwise to a heated (65-67°C) mixture of benzene (2 ml) and

and p-nitrobenzaldehyde (1.87 g, 12.37 mmol) over a period of 9 min. The resulting mixture was heated (67-70°C) and stirred for an additional 2.5 hr during which time a two-phase system was formed. Cooling in the refrigerator failed to produce a precipitate, only a trace of solid was formed on addition of ethanol (50 ml). The solution was evaporated under reduced pressure to yield a red-orange solid (1.56 g) whose infrared spectrum did not indicate the presence of bisbenzoin.

4.11 Attempted Preparation of m-Bis(phenylglyoxyloyl)benzene Employing Classical Benzoin Condensation

(a) Using Benzaldehyde

$$2\,C_6H_5CHO + m\text{-}C_6H_4(CHO)_2 \xrightarrow{KCN} m\text{-}C_6H_4[CH(OH)C(O)C_6H_5]_2 \xrightarrow{[O]} m\text{-}C_6H_5[C(O)C(O)C_6H_5]_2$$

To a stirred solution of isophthalaldehyde (4.11 g, 30.65 mmol) and benzaldehyde (6.77 g, 63.61 mmol) in ethanol (100 ml) was added a solution of potassium cyanide (2.0 g, 30.78 mmol) in water (25 ml). The alcoholic solution began to turn reddish orange as the potassium cyanide solution was added. The solution was heated at reflux (81-84°C) for 8.75 hr. A trace of deliquescent solid was obtained upon cooling. The now present two layers were separated. Addition of ether to the organic layer resulted in a separation of a solid (2.1 g) which did exhibit infrared absorptions indicative of the presence of hydroxyl and carbonyl groups. Oxidation of this material using the ammonium nitrate-cupric acetate-acetic acid system gave an oily solid which still contained in its infrared spectrum a hydroxyl absorption and whose spectrum did not bear any resemblance to that of authentic m-bis(phenylglyoxyloyl)benzene.[12]

The original ether soluble material also did not appear to contain the desired m-bisbenzoin.

(b) Using Benzoin[3]

$$C_6H_5C(O)CH(OH)C_6H_5 + m\text{-}C_6H_4(CHO)_2 \xrightarrow{KCN} m\text{-}C_6H_4[CH(OH)C(O)C_6H_5]_2$$

An aqueous solution (0.5 ml) of potassium cyanide (0.46 g, 7.06 mmol) was added to a heated (90°C) alcoholic solution (5 ml) of benzoin (0.50 g, 2.36 mmol) and isophthalaldehyde (0.33 g, 2.36 mmol). The resulting orange solution was heated at reflux (90-108°C) for 4.5 hr. The cooled solution was extracted with ether (2 x 10 ml). Removal of the solvent yielded a red-orange oil (0.92 g) which on oxidation with ammonium nitrate-cupric acetate-acetic acid based on infrared spectral analysis gave mostly benzil as well as a hydroxyl containing compound.

4.12 Preparation of Isophthalaldehyde bis-bisulfite Adduct

$$m\text{-}C_6H_4(CHO)_2 + 2\,NaHSO_3 \longrightarrow m\text{-}C_6H_4[CH(OH)SO_3Na]_2$$

To a solution of sodium bisulfite (15.6 g, 150.0 mmol) in water (25 ml) was added alcohol dropwise until cloudiness developed. Water was then added dropwise until the cloudiness just disappeared. To this solution was now added isophthalaldehyde (10.0 g, 74.6 mmol) and the resulting mixture stirred. A solution resulted as the bisulfite adduct is gradually formed. Upon continued stirring, a paste-like mixture started to appear. This mixture was filtered and the white solid washed with alcohol (2 x 5 ml), then dried to give a white powder (26.2 g, 103%); IR: 2.90 (OH), 8.35, 9.50 and 9.70μ (RSO_3Na).

4.13 Preparation and Isolation of Isophthalaldehyde bis-cyanhydrin

$$m\text{-}C_6H_4[CH(OH)SO_3Na]_2 + 2\,KCN \longrightarrow m\text{-}C_6H_4[CH(OH)CN]_2 + 2\,NaKSO_3$$

To a solution of isophthalaldehyde bis-sodium bisulfite adduct (4.00 g, 11.7 mmol) in water (15 ml), cooled in an ice bath, was added a solution of potassium cyanide (1.53 g, 23.4 mmol) in water (15 ml) over a period of 5 min. Subsequently, the solution was extracted with ether (3 x 20 ml) and dried over sodium sulfate. After removal of the ether in vacuo, a yellow liquid (1.64 g, 74.9% yield) was obtained; IR: 3.00 (OH) and 4.45μ (CN).

4.14 Reaction of in situ Generated Isophthalaldehyde bis-cyanohydrin With Benzaldehyde

The series of reactions performed is summarized in Table I; a typical reaction is described below.

To a stirred suspension of isophthalaldehyde bis-bisulfite adduct (2.0 g, 5.9 mmol) in water (5 ml) cooled in an ice bath was added a solution of potassium cyanide (0.78 g, 12.0 mmol) in water (5 ml) over a period of 2 min. The resulting solution was then added to stirred benzaldehyde (3.65 g, 34.4 mmol) at 81-87°C over a period of 9 min. Subsequently the reaction mixture was stirred at 84-87°C for 5.3 hr. The two layers that formed upon cooling were separated. The organic layer was distilled in vacuo (to remove excess benzaldehyde) giving 1.39 g of an amorphous solid. Treatment of the solid with ammonium nitrate-cupric acetate-acetic acid did not yield the desired m-bis(phenylglyoxyloyl)benzene.

4.15 Attempted Condensation of Isophthalaldehyde bis-cyanohydrin and Benzaldehyde

This series of reactions is summarized in Table II.

(a) Without Acid Acceptor

Under a nitrogen atmosphere a mixture of isophthalaldehyde bis-cyanohydrin (0.51 g, 2.73 mmol) and benzaldehyde (1.88 g, 17.67 mmol) was heated (69-73°C) with stirring for 7 hr. Subsequently, the unreacted benzaldehyde was distilled off in vacuo at final bath temperature of 97°C. The involatile residual oil (0.50 g, 98% yield) exhibited an infrared spectrum identical with that of the isophthalaldehyde bis-cyanohydrin.

(b) With Triethylamine as Acid Acceptor

To isophthalaldehyde bis-cyanohydrin (0.25 g, 1.33 mmol) dissolved in ethanol (1 ml) were added benzaldehyde (1.04 g, 9.81 mmol) and triethylamine (0.29 g, 2.87 mmol). The resulting solution was then stirred and heated at 86-91°C in an inert atmosphere for 8 hr. After removal of the benzaldehyde, ethanol, and triethylamine in vacuo at 104-115°C, an oil (0.45 g) remained which subsequently solidified. The infrared spectrum of this material exhibited hydroxyl and carbonyl functions; however, oxidation employing the ammonium nitrate-cupric acetate-acetic acid system failed to afford the desired m-bisbenzil. Addition of water to the oxidation mixture gave an orange oil whose infrared spectrum pointed to aromatic acids and/or aldehydes.

4.16 Preparation of Benzaldehyde Bisulfite Adduct

To a solution of sodium bisulfite (11.0 g, 0.11 mol) in water (40 ml) was added alcohol dropwise until cloudiness was observed. Water was then added dropwise until the cloudiness cleared. To this solution was added benzaldehyde (10.4 g, 0.1 mol) and the resulting mixture stirred. Upon continued stirring, a paste-like material formed which was subsequently filtered, washed with a minimum amount of cold water and dried to give a white powder (15.8 g, 76.7% yield); IR: 2.97 (OH), 8.25 and 9.65μ (RSO_3Na).

4.17 Attempted Preparation of m-$C_6H_4[CH(OH)C(O)C_6H_5]$. Reaction of Benzaldehyde cyanohydrin (Mandelonitrile) and Isophthalaldehyde

The series of reactions performed is summarized in Table III; a typical reaction is described below.

An aqueous solution (5 ml) of potassium cyanide (0.62 g, 9.52 mmol) was added to a cooled (0°C) suspension of benzaldehyde bisulfite adduct (2.00 g, 9.52 mmol) in water (10 ml). The suspension was slowly transformed into mandelonitrile which separated as an oil. A benzene solution of isophthalaldehyde (0.63 g, 4.72 mmol) was then added dropwise. The resulting mixture was stirred and heated (61-93°C) for 2 hr under nitrogen atmosphere. During the heating period, a dark red solid separated. The cooled mixture was filtered and the solid washed with benzene. The infrared spectrum of the solid (0.68 g, corresponding to 109.4% of isophthalaldehyde employed) possessed multiple carbonyl absorbances but no bands indicative of a bis-benzoin structure. The benzene layer was separated, washed with water (2 x 20 ml) then dried over anhydrous magnesium sulfate. The drying agent was subsequently removed by filtration and the solvent evaporated under reduced pressure. The residual oil (0.95 g)

was shown by its infrared spectrum to consist essentially of benzaldehyde; the 0.95 g corresponds to 94% of the mandelonitrile originally used.

4.18 Attempted Preparation of $m\text{-}C_6H_4[C(O)CH(OH)C_6H_4NO_2\text{-}p]_2$

The cold aqueous solution of isophthalaldehyde bis-cyanohydrin prepared from isophthalaldehyde bis-bisulfite adduct (2.00 g, 5.84 mmol) and potassium cyanide (0.76 g, 11.68 mmol) was added dropwise over a period of 10 min to heated p-nitrobenaldehyde (1.77 g, 11.68 mmol). The orange mixture was heated (67-78°C) for an additional 4.7 hr then cooled to ambient temperature. The solvent was removed under reduced pressure to yield an amorphous solid which was treated, in succession, with benzene (12 x 10 ml), ether (8x 15 ml) and hot ethanol (10 x 10 ml). Neither the extracted material (120, 20 and 210 mg, respectively) nor the now powdery residue possessed an infrared spectrum indicative of the desired m-bisbenzoin.

4.19 Attempted Preparation of $m\text{-}C_6H_4[C(O)C(O)C_6H_4Cl\text{-}p]_2$

A cold aqueous solution (30 ml) of isophthalaldehyde bis-cyanohydrin prepared from isophthalaldehyde bis-bisulfite adduct (6.01 g, 17.56 mmol) and potassium cyanide (2.29 g, 35.12 mmol) was added dropwise over 15 min to heated (72°C) p-chlorobenzaldehyde (5.11 g, 36.35 mmol). The resulting two-phase system was heated (66-72°C) with stirring for 3.5 hr, then cooled. The aqueous layer was decanted and the semi-solid organic phase washed with water (2 x 10 ml) which upon treatment with ether (8 x 15 ml) was transformed into a powder (2.83 g). The ethereal solution on evaporation yielded an orange oil residue (5.24 g).

Oxidation of the powder (1.0 g) with ammonium nitrate (1.0 g, 12.61 mmol) and cupric acetate (22.6 mg) in 80% acetic acid (5 ml) yielded a product (0.46 g) whose infrared spectrum was essentially identical with the unoxidized material. Oxidation of the oil (1.92 g), with ammonium nitrate (1.96 g, 24.48 mmol) and cupric acetate (80 mg) in 80% acetic acid (7 ml), gave a yellow powder (0.3 g), mp 181-185°C. This material was purified by sublimation: mp 192-193.5°C; IR: 5.99 and 8.21 (aromatic CO) and 9.08μ (aromatic halide). Material was identified to be p,p'-dichlorobenzil by infrared spectral analysis.

4.20 Preparation of Phthalaldehyde bis-bisulfite Adduct

$$o\text{-}C_6H_4(CHO)_2 + NaHSO_3 \longrightarrow o\text{-}C_6H_4[CH(OH)SO_3Na]_2$$

Sodium bisulfite (15.65 g, 0.15 mol) was dissolved in 25 ml water in a 200 ml round bottom flask. To this solution was then gradually added phthalaldehyde (10.04 g, 0.08 mol) and the solution warmed in an oil bath (53-73°C) for 3 hr. The tan cake that formed within 40 min was dissolved by the addition of water (25 ml). The solution was then partially cooled and filtered to remove a small amount of insoluble material. This was followed by alcohol addition until the hot solution just became cloudy. The white solid that formed on cooling was filtered and air dried (22.15 g, 86.5%) and exhibited the following: IR: 2.95 (OH) 8.35 and 9.85μ (RSO_3Na).

4.21 Attempted Preparation and Isolation of Phthalaldehyde bis-cyanohydrin

$$o\text{-}C_6H_4[CH(OH)SO_3Na]_2 + 2\,KCN \longrightarrow o\text{-}C_6H_4[CH(OH)CN]_2 + 2\,NaKSO_3$$

To a stirred suspension of phthalaldehyde bis-bisulfite adduct (2.0 g, 5.86 mmol) in water (10 ml), cooled in an ice bath, was added a solution of potassium cyanide (0.75 g, 11.51 mmol) in water (10 ml) over a period of 3 min. The solution became yellow

almost immediately. Extraction with ether (2 x 5 ml) followed by solvent removal gave a brown liquid residue (0.31 g). This material exhibited an infrared spectrum unrelated to that of the bis-cyanohydrins of the para or meta isomers; no nitrile band was observed.

4.22 Attempted Preparation of o-$C_6H_4[C(O)C(O)C_6H_5]_2$. Reaction of in situ Generated Phthalaldehyde bis-cyanohydrin and Benzaldehyde

A series of reactions was performed and these are summarized in Table IV; typical reactions are described below.

a) In the Absence of Solvent

Potassium cyanide (1.14 g, 17.54 mmol), dissolved in 10 ml water, was added to a cooled (1°C) aqueous solution of phthalaldehyde bis-bisulfite adduct (3.01 g, 8.79 mmol) during a 5 min period. The yellow mixture was transferred to an addition funnel and then, under a nitrogen atmosphere, added to benzaldehyde (5.73 g, 54 mmol) heated at 79-80°C. Upon completion of addition, the resulting mixture was heated at 65-80°C for 3.9 hr. After cooling the organic layer was separated and washed with water (3 x 20 ml). The excess benzaldehyde and residual water were removed by vacuum distillation. The residual viscous red oil (1.50 g) showed in its infrared spectrum absorbances at 3.05 (OH), 5.95 (center of broad absorbance, CO) and 10.25μ; the latter indicating the presence of a benzoin type of structure.

The oil was dissolved in 80% acetic acid (4 ml) followed by addition of ammonium nitrate (1.50 g, 19 mmol) and cupric acetate (10 mg). The resulting solution was heated at 98-109°C for 3.8 hr. After cooling, filtration yielded only trace amounts of crystalline material. Addition of water to the filtrate caused the separation of a dark red oil which solidified upon trituration with ether; IR: 3.10 (OH) 5.95μ (center of broad absorbance; CO).

b) Using Ethanol as Solvent

To a cold (-20 to -12°C) 33% aqueous ethanol solution of 1,2-$C_6H_4[CH(OH)SO_3Na]_2$ (2.00 g, 5.86 mmol) was added a cold aqueous ethanol solution of potassium cyanide (0.77 g, 11.76 mmol). The solution was stirred for 10 min, during which time it became light yellow and opaque. The solution was subsequently added all at once to cold (-10°C) benzaldehyde (11.87 g, 0.11 mol). The mixture was then stirred for 2 hr at -10° to -4°C, then at 0-5°C for an additional 2 hr and finally at ambient temperature (27°C) for 30 min. The color changed from yellow to orange and finally to red as the mixture was stirred at the three different temperatures. The resulting two-phase system was extracted with ether (3 x 10 ml). The extracts were washed with water (3 x 30 ml), dried over anhydrous magnesium sulfate then filtered. The ether was removed under reduced pressure to give a red oil. Cooling overnight in the refrigerator did not yield any crystalline material. Excess benzaldehyde was removed by vacuum distillation and oxidation of the residual oil (1.47 g) gave 58.6 mg of a red-yellow solid, mp > 200°C; based on its infrared spectrum it appeared to be inorganic in nature. Addition of water to the filtrate gave, after prolonged standing, a red oil whose infrared spectrum indicated the presence of hydroxyl and carbonyl moieties.

4.24 Preparation of p-$C_6H_4[CH(OH)CO_2H]_2$

$$p\text{-}C_6H_4[CH(OH)SO_3Na]_2 \xrightarrow{KCN} p\text{-}C_6H_4[CH(OH)CN]_2 \xrightarrow[(dil)]{HCl} p\text{-}C_6H_4[CH(OH)CO_2H]_2$$

A cold aqueous solution of potassium cyanide (2.03 g, 31.13 mmol) was added dropwise to an aqueous suspension of terephthalaldehyde bis-bisulfite adduct (5.01 g, 14.63 mmol) cooled in a 0°C bath. The resulting mixture was stirred until a clear solution was obtained. The aqueous solution was then extracted with ether (2 x 20 ml) and the combined extracts were washed with water

(2 x 20 ml). After removal of ether to the resulting yellow-orange oil was added dilute hydrochloric acid (40 ml) and the solution was heated at 83-115°C for 3 hr. On cooling a white powder (1.83 g) was obtained which was crystallized from acetone giving p-$C_6H_4[CH(OH)CO_2H]_2$ (1.07 g, 32.4%): mp > 290°C;[2] IR: 2.94 (OH), 3.25-4.00 (CH, COOH) and 5.75μ (CO): DSC, Figure 1; TGA, Figure 2. Anal. Calcd for $C_{10}H_{10}O_6$: C, 53.10; H, 4.46. Found: C, 53.37; H, 4.60.

4.25 Preparation of m-$C_6H_4[CH(OH)CO_2H]_2$

$$m\text{-}C_6H_4[CH(OH)SO_3Na]_2 \xrightarrow{KCN} m\text{-}C_6H_4[CH(OH)CN]_2 \xrightarrow[(conc)]{HCl} m\text{-}C_6H_4[CH(OH)CO_2H]_2$$

To a cooled aqueous solution of isophthalaldehyde bis-bisulfite adduct (2.02 g, 5.89 mmol) was added a cold solution of potassium cyanide (0.82 g, 12.5 mmol). The resulting solution was stirred at 0°C for 10 min, then extracted with ether (2 x 10 ml). Subsequently, ether solvent was removed in vacuo to yield a red brown oil (it should be noted that treatment of the ethereal solution with decolorizing carbon resulted in light yellow product) to which was added concentrated hydrochloric acid (5 ml). The solution was then stirred at ambient temperature for 2 hr. Evaporation of the solvent left a yellow amorphous residue which was triturated with acetone. The mixture was filtered and the solvent removed under reduced pressure to give a red oil (1.31 g) which was acidic to pH paper. The crude acid was purified by dissolving in 5% sodium hydroxide, decolorization, then acidification with dilute hydrochloric acid. Evaporation of the solvent yielded a light yellow oil (0.99 g, 74.4%). The solid acid m-$C_6H_4[CH(OH)CO_2H]_2$ was obtained with great difficulty from a minimum volume of ethanol-acetone (216 mg gave 85 mg), mp 157.5-159.5°C; IR: 2.97 (OH), 3.25-4.25 (CH, COOH) and 5.75μ (CO): DSC, Figure 3; TGA, Figure 4. Anal. Calcd for $C_{10}H_{10}O_6$; C, 53.10; H, 4.46. Found: C, 53.25; H, 4.71.

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6. TECHNOLOGICAL FORECAST

6.1 Problem

Two major problems exist in the application of presently available polyquinoxalines. The first arises from the very low solubility of polyphenylquinoxaline. Thus, in order to obtain prepreg solutions of reasonable solids concentration relatively involatile and therefore hard to remove solvents such as cresols must be employed. The second major problem is associated with the high glass transition temperature of polyphenylquinoxaline which necessitates high processing pressures and temperatures. A further shortcoming of the polyquinoxaline system is the high cost of the required bis(phenylglyoxyloyl)benzene comonomers and the unavailability of functional derivatives of these materials which would permit flexibility in tailoring processing and physical and mechanical characteristics of the polyquinoxaline system. For example, it would be desirable to initially prepare prepolymers which are capable of chain extension and/or crosslinking, to allow modifications of chain conformation thus to further increase composite strength, toughness, char yield, and ablation performance, or to improve adhesive properties and film and fiber forming characteristics.

6.2 State of Technology

Under Contract N00017-73-C-4325 a process was developed by which 1,4-bis(phenylglyoxyloyl)benzene became available at less than $100/lb in materials cost and possibly as low as $10/lb by large scale production. During the present program this process was successfully employed to synthesize the p-chloro, p-methoxy, and p-hydroxy derivatives of 1,4-bis(phenylglyoxyloyl)benzene, thus these materials are potentially available in the same price range. Although all attempts made to extend this process to the production of the 1,3- and 1,2-isomers of bis(phenylglyoxyloyl)benzene have failed thus far, the process

did yield a stable m-bis-cyanohydrin which has a promise as an intermediate for the preparation of comonomers which would be most useful in the modification of PPQ-type polymers.

6.3 Suggestions, Forecast and Implications

To fully exploit the potential of polyphenylquinoxalines not only as advanced reentry vehicle heat shield matrix resins but also as components of flame resistant fabrics, protective coatings, high temperature adhesives, thermally stable load carrying structures, or energy absorbing systems, it is necessary to make available at reasonable costs p-bis-benzil isomers and derivatives which will provide a selection of comonomers to impart or enhance the particularly desired properties such as, e.g., improved processing characteristics, increased char yield, better adhesion, or greater strength. In order to prove the feasibility of tailoring the resin properties, it is furthermore necessary to scale up the synthesis of the derivatives prepared during the present program to make the materials available in quantities sufficient for polymer production and evaluation. Finally, it is believed that the m-biscyanohydrin prepared under this contract merits consideration as a potential comonomer precursor.

Pursuing the synthesis studies of p-bis-benzil isomers and suitably substituted derivatives can be expected, based on the results obtained so far, to lead to the development of a broad spectrum of thermally stable polyquinoxaline type resins with better handling and processing characteristics and with properties tailored for a variety of applications. In regard to improved processibility higher solids loadings of the prepreg solution, use of more volatile solvents, lower curing temperatures and pressures, and the possibility of employing prepolymers must be mentioned. The flexibility in tailoring resin properties, gained by having available p-bis-benzil isomers and derivatives, in turn must be expected

to lead to the utilization of polyphenylquinoxalines in applications, for which the resin properties until now were inferior or insufficient. Among these are, as already pointed out, flame resistant fibers and coatings, energy absorbing and dissipating systems components, or e.g., high strength-low weight structures, which possibly could replace metal assemblies where for example corrosion is a problem; this all in addition to the presently contemplated application in load carrying heat shields. It should be possible to develop all the necessary technological background within a 1-3 year period to allow utilization of thus modified and improved polyquinoxalines in operational systems.

The return of such a program in terms of lower costs and/or higher performance in novel utilization areas of polyquinoxalines such as for the purpose of flame or corrosion resistance can at present only be speculated upon. However, in those applications, where combined ablation and high temperature structural performance are required, utilization of polyphenylquinoxaline/carbon composites for integrated heat shield structures is expected to reduce the weight of this subsystem 30 to 50%, as compared to a conventional carbon/phenolic over aluminum subsystem. The broad systems implications are increased range and improved hardness without weight penalty. Estimated weight savings are conservatively 10% of vehicle weight for those in the 250 to 350# weight range which is achieved by reducing insulation, allowing higher back face temperatures, and eliminating the bond. In terms of fleet performance criteria the value of these improvements is estimated to be between 0.25 and 0.5 billion dollars. The current emphasis on accuracy and terminal maneuvering capability will put a further premium on high temperature-high performance-reduced weight capabilities of subsystems because of the increased weight of the guidance package.

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13. ABSTRACT

The goal of this investigation was to apply the modified benzoin condensation, used successfully in the synthesis of unsubstituted para-bis(phenylglyoxyloyl)benzene, to the preparation of substituted para-derivatives as well as to the production of selected meta and ortho isomers.

Using this process the substituted compounds: p-bis(p-methoxyphenylglyoxyloyl) benzene, p-bis(p-hydroxyphenylglyoxyloyl)benzene, and p-bis(p-chlorophenyl-glyoxyloyl)benzene, were obtained in yields of 41, 16, and 46%, respectively. The formation of the bis-cyanohydrin intermediate was unequivocally proven by its transformation to the para-bis-hydroxy acid.

The extension of the modified benzoin reaction to the synthesis of meta and ortho isomers of p-bis(phenylglyoxyloyl)benzene was to date unsuccessful. In the case of isophthalaldehyde the intermediate bis-cyanohydrin was unexpectedly stable, which under the conditions employed prevented its condensation with benzaldehyde. This material was characterized by the hydrolysis to the meta-bis(hydroxy acid). Reaction of benzaldehyde cyanohydrin with isophthalaldehyde resulted in hydrogen cyanide exchange and formation of the bis-cyanchydrin of isophthalaldehyde and benzaldehyde. The cyanohydrin derived from phthalaldehyde appeared to undergo self-condensation above 0° C; at lower temperatures no reaction with benzaldehyde occurred.

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1,4-bis(p-hydroxyphenylglyoxyloyl)benzene						
p-bisbenzils						
p-bisbenzoins						