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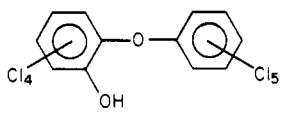
Photochemistry of Polychlorinated Phenoxyphenols: Photochemistry of 3,4,5,6-Tetrachloro-2-(pentachlorophenoxy)phenol

Peter K. Freeman* and Ramanujan Srinivasa

The 3,4,5,6-tetrachloro-2-(pentachlorophenoxy)phenol, a major contaminant in technical pentachlorophenol, was synthesized and its photochemistry studied at 300 nm in cyclohexane and acetone solvents. Its photochemistry was also studied in cyclohexane with *m*-methoxyacetophenone as a sensitizer. The results show that in the direct irradiation cleavage of the ether bonds and reductive dechlorination represent the major reaction pathways. On the other hand, photocyclization occurs in both acetone and cyclohexane in the presence of *m*-methoxyacetophenone as a sensitizer. The extent of photocyclization is much higher in acetone. The presence of an electron-transfer agent, triethylamine, enhances cyclization in the sensitized process. The mechanistic implications are discussed.

The impetus for an investigation of the excited state chemistry of chlorinated phenoxyphenols stems from the fact that the three isomeric perchlorophenoxyphenols (1, 2, and 3) represent major impurities in pentachlorophenol (Rappe and Nilsson, 1972; Jensen and Renberg, 1972; Nilsson and Renberg, 1974; Deinzer et al., 1978, 1979, 1981). Since these species all absorb in the sunlight range and their chemical construction is such as to suggest ready cyclization, the potential for photochemical conversion to highly toxic chlorinated dibenzo-*p*-dioxins and chlorinated dibenzofurans is clear. This report describes our exploration of this potential for ortho isomer 1.



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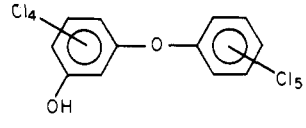

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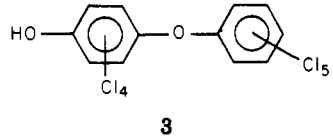

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EXPERIMENTAL SECTION

Materials. Spectrograde cyclohexane (Mallinckrodt) was redistilled and no detectable impurity was found by GLC. Spectrograde acetone (Baker) and *m*-methoxyacetophenone (Aldrich, 99%) were used as sensitizers without further purification.

Product Analyses. The photoproducts were identified by comparing their GLC retention times with those of known compounds and by mass spectrometry. Gas–liquid chromatographic analysis of the photolysates was carried out on a Varian 3700 gas chromatograph equipped with a flame ionization detector. A 5-ft copper column of 0.56% SE-30 on Anakrom-AS (110–120 mesh) was used. Unless otherwise mentioned, the temperature of the column was programmed from 55 to 220 °C at 10 °C/min. Helium carrier gas flow rate was approximately 60 mL/min. The response factors for known compounds were determined by using dodecane as the internal standard. Whenever authentic standards were unavailable, response factors were estimated on the basis of similarities in structure and molecular weight, either to pentachlorophenol or to predioxin 1. For example, the response factor for octachloro-2-phenoxyphenol **22** was considered the same as that for predioxin 1.

Mass spectral analyses of the photolysis mixtures were done at 70 eV electron energy either on Varian CH-7 mass spectrometer equipped with a System Industries 150 data analyzer and a Varian 1200 series gas chromatograph or on a Finnigan 4023 mass spectrometer equipped with a Finnigan 9610 gas chromatograph. The column and the GLC conditions were the same for both GLC and GLC–MS analyses.

In the case of the lower chlorinated dioxins and predioxins, an effort was made to identify them with the limited data available. Wherever authentic samples were available the GLC retention times were compared and the mass spectra matched to confirm the structures. However, in certain cases, owing to the unavailability of authentic samples, mass spectral analysis was used to determine the structures partially (i.e., from which of the two phenyl rings the chlorine atom was lost).

Thus, the octachlorodibenzodioxin **27** was identified by comparing both its GLC retention time and the mass spectrum with those of an authentic sample. Comparison of the mass spectra and the GLC retention times of the

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two heptachlorodibenzodioxins with those reported in the literature (Buser, 1975a,b) indicated the presence of four chlorines on one ring and three on the other. Since there can exist only two isomers, the two structures correspond to **24** and **25**, respectively; the GLC retention time of the former is shorter. For the two hexachlorodibenzodioxins, mass spectral comparison indicated that each phenyl ring contained three chlorine atoms. In all eight isomers being possible, the structures of the two hexachlorodibenzodioxins in question are designated as **23a** and **23b**.

Among the various possible dechlorination products of predioxin, only one heptachloro- and three octachloro-2-phenoxyphenols were observed. The mass spectral fragmentation pattern of the heptachloro predioxin showed an intense cluster of peaks (*m/e* 248) corresponding to an ether cleavage fragment containing five chlorine atoms. Consequently, the two chlorine atoms are lost from the phenolic ring. Thus, the compound designated as **19** corresponds to one of the six possible isomers. As for the three octachloropredioxins, mass spectral analysis and comparison with spectra reported in the literature (Deinzer et al., 1979) showed that only one of them gave a fragment (*m/e* 214) that indicated the loss of a chlorine atom from the phenyl ring. Thus, its structure, designated as **22**, corresponds to one of the three isomers. The other two gave a fragment (*m/e* 248) that was indicative of the loss of a chlorine atom from the phenolic ring. Of the four possible isomers, the two compounds in question correspond to **20a** and **20b**, respectively, where the former has a shorter retention time.

Synthesis of 3,4,5,6-Tetrachloro-2-(pentachlorophenoxy)phenol (1). The polychlorinated phenoxyphenol 1 was synthesized from pentachlorophenol by a two-step reaction adapting the methods of Reed (1958) and Deinzer (1981).

*Preparation of 2,3,4,5,6-Pentachloro-4-(pentachlorophenoxy)-2,5-cyclohexadienone (**34**).* To a mechanically stirred mixture of pentachlorophenol (PCP; 13.2 g, 0.25 mol), trifluoroacetic acid (37.6 mL), and trifluoroacetic acid anhydride (56.3 mL) under a nitrogen atmosphere, fuming nitric acid (10.5 mL; sp gravity 1.6) was added dropwise over 15 min while cooling the reaction mixture in an ice–salt bath (ca. −20 °C). Within minutes the mixture turned orange-red. Stirring was continued for 4 h at ca. −20 °C. The cooling of the mixture was necessary in order to avoid violent exothermic decomposition of the reaction products in the presence of nitric acid at about 0 °C resulting in the formation of high-melting bright red solids which are probably nitro derivatives. The cold reaction mixture was rapidly filtered through a fritted funnel by using a water aspirator and the orange-red residue was washed with three 30-mL portions of chilled diethyl ether in order to remove any nitric acid still associated with the residue. Complete removal of the nitric acid was important because it is very likely to react violently with the products above −10 °C. Moreover, since ether itself, by virtue of the C–H bonds it contains, reacts with the dienone at 0 °C, it was necessary to chill it before its use to minimize the loss of the product during washing. The orange-red solid was crystallized from boiling carbon tetrachloride to give an amorphorus solid (yield 7.5 g, 57%): mp 172–173 °C (lit. mp 177–178 °C) (Reed, 1958); IR (KBr) 1705, 1685, 1575 cm^{-1}.

*Reduction of Dienone **34** to Predioxin **1**.* Dienone **34** (5.3 g, 10 mmol) was weighed into a three-necked flask (3 L) and 2000 mL of carbon tetrachloride (Baker reagent grade) was added. The mixture was stirred to give an orange-yellow solution. Nitrogen gas was passed into the solution in a thin stream throughout the reaction. Sodium iodide (1.5 g, 20 mmol) was dissolved in a small volume of absolute methanol and the solution was diluted to 200 mL. To this was added 200 mL of chloroform (reagent grade) and the resulting solution was thoroughly stirred and then transferred to a dropping funnel (500 mL) that was fitted to the reaction flask. The iodide solution was now added slowly to the dienone solution over a period of 1 h while stirring continuously. The entire solution turned deep red after adding a few milliliters of the iodide solution. Stirring was maintained for 24 h. The dark-red solution was concentrated on a rotaevaporator to about 25 mL. After initial TLC analysis, which showed the presence of the desired product, the mixture was treated with 1 N NaOH until slightly basic when it turned pale orange. The solution was extracted with ether, and the ether solution, after it had been washed with 1 N HCl and water until it was neutral, was dried ($MgSO_4$). The ether solution was finally evaporated to give a dark red solid (3.2 g, 73.9%).

Isolation of Predioxin. The dark red solid was dissolved in a mixture of methylene chloride and methanol (9:1 v/v), and thin-layer chromatography on silica gel with a hexane, methylene chloride, and 2-propanol mixture (5:4.9:0.1 v/v) as the eluant showed the presence of pentachlorophenol (R_f 0.236), predioxin (R_f 0.38), and the dienone (R_f 0.56) besides other products. In order to remove the ionic impurities, the crude reduction mixture was subjected to ion-exchange chromatography. A glass column (internal diameter = 4.1 cm) was filled with a slurry of Dowex 1 × 4 anion-exchange resin (50–100 mesh), which had been previously treated with 1 N NaOH for 2 h for activation, until a length of 6 in. was reached. The resin was washed with water until it was free of the base. It was then washed with methanol (absolute) until it was free of water. The reduction mixture was now placed on the column and eluted first with a mixture of chloroform and methanol (1:9 v/v). The presence of chloroform was necessary in order to prevent the product components from precipitating. Thin-layer chromatographic analysis on silica gel with the hexane, methylene chloride, and 2-propanol mixture (5:4.9:0.1 v/v) as the eluant indicated the presence of the dienone **34** in the second and, to some extent, in the third fractions. When all the dienone had been eluted, the remaining components were eluted with 2 N acetic acid in absolute methanol. Several fractions were collected and all these showed the presence of predioxin. Since the last two fractions were found to contain a very small amount of predioxin and traces of pentachlorophenol, these were rejected and the other fractions were combined together to give a total volume of 2 L, which was concentrated to about 50 mL. The ion-exchange chromatography proved to be very convenient in the separation of predioxin from pentachlorophenol since the latter is more strongly adsorbed to the resin. The concentrated predioxin fraction was further evaporated to give a white solid (3.12 g). The solid was rechromatographed on silica gel (300 g) by using a hexane, methylene chloride, and 2-propanol mixture (7.0:2.5:0.5 v/v) to give almost pure predioxin (yield 2.95 g, 59.5%). Recrystallization from hexane gave a white solid with mp 198–200 °C.

Spectral Analyses. A UV spectrum of a cyclohexane solution of predioxin (2.016×10^{-4} M) exhibited maxima at 290 (ϵ = 2530) and 299 nm (ϵ = 2837). The mass spectrum of predioxin was found to be identical with that reported in the literature (Buser, 1975a; Deinzer et al., 1978; Rappe and Nilsson, 1972). A cluster of seven lines (*m/e* 492–504) differing by two mass units indicated the presence of nine chlorine atoms with the molecular ion

Table I. Quantities of Predioxin 1 and Dodecane Used in the Cyclohexane Photolyses

photolysis mixture	0.5 h		1 h		4 h		8 h	
	mg	μmol	mg	μmol	mg	μmol	mg	μmol
predioxin	19.0	38.3	25.0	50.4	20.46	41.25	20.46	41.25
dodecane	11.7	68.8	15.0	88.2	9.0	52.9	9.0	52.9

peak at m/e 492. The other characteristic masses observed were at m/e 456 ($M^+ - HCl$), 422 ($M^+ - 2Cl$), and 248 ($M^+ - C_6O_2Cl_4$).

Synthesis of 3,4,5,6-Tetrachlorocatechol, 17. A mixture of 3,4,5,6-tetrachloro-*o*-benzoquinone (1.0 g, 4.07 mmol), 1,4-cyclohexadiene (0.65 g, 8.14 mmol), and toluene (dry, distilled, 50 mL) was heated at reflux under a nitrogen atmosphere. The initially formed dark red solution soon turned pale yellow and eventually colorless over a period of 1 h. Heating at reflux was extended for an additional hour to ensure complete reduction. The reaction mixture was cooled and evaporated to give a white solid (1.0 g). The impure solid was recrystallized from aqueous ethanol (7 parts of water and 3 parts of ethanol) and its melting point determined, mp 192–194 °C (lit. mp 194–195 °C) (Zincke and Küster, 1888) yield 0.98 g (97%). Mass spectral analysis revealed a cluster of peaks at masses 246–252, indicating the presence of four chlorine atoms with the molecular ion peak at m/e 246. Other significant peaks were 210 ($M^+ - HCl$) and 248 (base peak); m/e 49 (9%), 60 (5.9%), 77 (9.2%), 87 (22.2%), 95 (7.9%), 111 (30.4%), 147 (33.0%), 210 (11.0%), 246 (88.7%), 248 (100%), 250 (44.7%), and 252 (9.3%).

General Photolysis Procedure. The photolysis of predioxin 1 was carried out in a Rayonet merry-go-round photochemical reactor (The Southern New England Co.) equipped with eight 3000-Å Rull lamps. The temperature of the reactor chamber was kept constant at 45 °C by passing a stream of air through the apparatus. The photolysis samples were placed in quartz tubes (170 mm × 15 mm) with Pyrex glass sliding stoppers and degassed through three or four freeze–pump–thaw cycles and sealed in vacuo prior to irradiation. Quantum yields of the photoproducts were determined by using the photoconversion of cyclopentanone to 4-pentenal as the actinometer.

Photolysis of Predioxin 1 in Cyclohexane. Four samples of predioxin 1 in 5.0 mL of cyclohexane were prepared. Dodecane was added to each of them. The quantities of the substances in these samples are shown in Table I. These were degassed and irradiated for 0.5, 1, 4, and 8 h, respectively. The photolysis mixtures were analyzed by GLC and mass spectrometry.

Photolysis of Predioxin in Acetone. A 5.0-mL acetone solution of predioxin (20.75 mg, 41.8 mmol) and dodecane (15.0 mg, 88.2 mmol) was degassed and irradiated for 4 h.

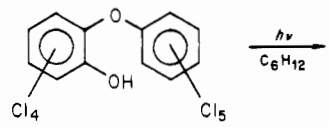
Photolysis of Predioxin in Cyclohexane with *m*-Methoxyacetophenone as Sensitizer. Three 5.0-mL solutions each containing predioxin (41.1 μmol), dodecane (14.0 μmol), and *m*-methoxyacetophenone (666 μmol) in cyclohexane were degassed and photolyzed at 300 nm for 6 h. Three 5.0-mL samples of cyclopentanone in cyclohexane each containing 5.0 mmol of cyclopentanone [$\Phi = 0.37 \pm 0.01$ (313 nm) (Dunion and Trumbore, 1965)] and 0.0288 mmol of dodecane (internal standard) were degassed and photolyzed simultaneously for 6 h with the three *m*-methoxyacetophenone-sensitized predioxin samples.

RESULTS AND DISCUSSION

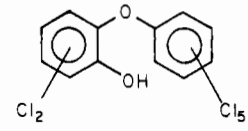
Since the *o*-hydroxy isomer, predioxin 1, exhibits a $\lambda_{max} = 299$ nm, the chemical consequences of excitation at 300 nm were investigated. Irradiation of predioxin 1 in cyclohexane for 0.5, 1.0, 4.0, and 8.0 h generated the array of products illustrated in Scheme I and Table II. The major reaction pathways are clearly (a) reductive dechlorination leading to chlorinated ethers **19**, **20a**, and **20b** and (b) ether cleavage producing pentachlorophenol (**16**), tetrachlorocatechol (**17**), pentachlorobenzene (**15**), and daughter dechlorination products of **15**. No evidence of electrocyclic ring closure to dibenzo-*p*-dioxins or dibenzofurans was observed.

In contrast to the results of direct irradiation, photolysis of predioxin 1 (a) in acetone and (b) in cyclohexane with

Scheme I



(A) dichlorobenzenes (**6–8**)
(B) trichlorobenzenes (**9–11**)
(C) tetrachlorobenzenes (**12–14**)
(D) pentachlorobenzene (**15**)
(E) chlorinated phenols (**16–18**)
(F) dechlorinated predioxins (**19**, **20a**, and **20b**)



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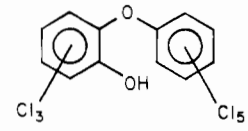


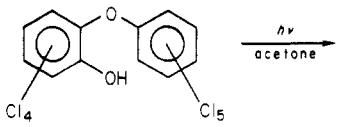
20a, 20b

Table II. Photolysis of Predioxin 1 in Cyclohexane at 300 nm

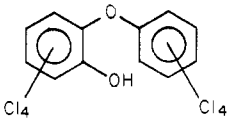
photoproduct	yield, mol %[a]			
	0.5 h	1 h	4 h	8 h
4, chlorocyclohexane	4.4	45.1	55.0	73.3
5, dicyclohexyl	20.9	6.1	11.2	12.7
6, 1,3-dichlorobenzene[b]	1.1	0.7	0.6	0.0
7, 1,4-dichlorobenzene[b]				
8, 1,2-dichlorobenzene	0.9	1.1	0.0	0.0
9, 1,3,5-trichlorobenzene	2.8	1.9	1.6	1.7
10, 1,2,4-trichlorobenzene	3.3	1.8	2.7	2.9
11, 1,2,3-trichlorobenzene	7.4	4.0	0.0	0.0
12, 1,2,3,5-tetrachlorobenzene[b]	8.1	5.1	4.2	4.5
13, 1,2,4,5-tetrachlorobenzene[b]				
14, 1,2,3,4-tetrachlorobenzene	5.4	4.0	6.2	6.3
15, pentachlorobenzene	2.6	1.9	2.7	3.4
16, pentachlorophenol	2.3	9.0	13.8	25.1
17, tetrachlorocatechol	4.0	0.3	7.4	13.5
18, cyclohexyltetrachlorophenol	2.6	3.6	8.2	10.3
19, heptachloro-2-phenoxyphenol	0.0	0.0	0.3	4.2
20a, octachloro-2-phenoxyphenol (isomer A)	11.4	7.3	12.5	19.3
20b, octachloro-2-phenoxyphenol (isomer B)	6.0	1.0	3.2	17.0

[a] Yields are reported on the basis of moles of product formed per mole of predioxin consumed and were determined by using dodecane as an internal standard in the GLC analysis. The yields of the recovered predioxin for the four reactions were 64.6%, 57.1%, 18.6%, and 14.9%, respectively. [b] The GLC peaks for 1,3- and 1,4-dichlorobenzenes as well as those for 1,2,3,5- and 1,2,4,5-tetrachlorobenzenes could not be resolved on a SE-30 column which proved to be the best choice for the analysis.

Scheme II



(A) pentachlorobenzene (15)
(B) chlorinated phenols (16, 21)
(C) dechlorinated predioxins (19, 22)



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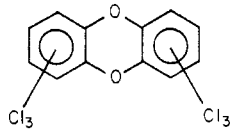
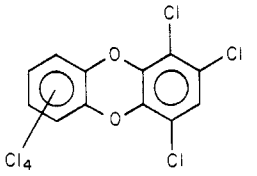
(D) chlorinated dibenzodioxins (23a, 23b, 24, 25, 27) and heptachlorodibenzofuran (26)



23a, 23b



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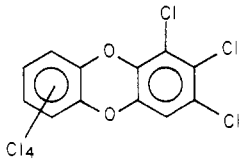

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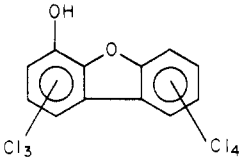

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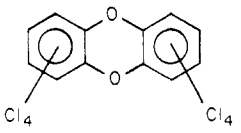

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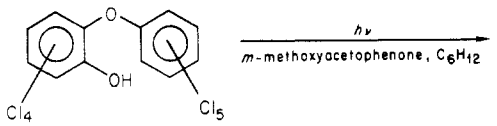
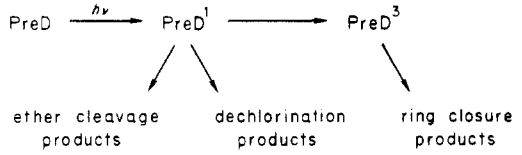
Scheme III



(A) pentachlorobenzene (15)
(B) chlorinated phenols (16, 18)
(C) chlorinated dibenzodioxins (24, 27) and heptachlorodibenzofuran (26)
(D) dechlorinated predioxins (19, 20a, 20b, 22)

Scheme IV



m-methoxyacetophenone as the sensitizer revealed that cyclization to dibenzo-*p*-dioxins and dibenzofuran was either the major pathway (acetone) or a substantial contributor (*m*-methoxyacetophenone) (Schemes II and III and Tables III and IV).

These results strongly suggest that the triplet excited state is responsible for cyclization to dibenzo-*p*-dioxins and dibenzofuran with singlet state generating ether cleavage and dechlorination products (Scheme IV). Choudhry et al. (1977) have also observed enhanced cyclization to dibenzofuran for some chlorinated diphenyl ether substrates in the presence of acetone sensitizer.

Since the C–Cl bond energy is approximately 95 kcal/mol (Egger and Cocks, 1973) and the triplet energy level is of the order of 72 kcal/mol or less, the reaction pathway to the dioxins cannot involve a simple C–Cl bond homolysis followed by ring closure. An electron transfer followed by C–Cl cleavage of the radical anion seems likely (Ohashi et al., 1973; Bunce et al., 1975, 1976, 1978; Ruzo et al., 1975; Chitten et al., 1978; Davidson and Goodin, 1981; Grimshaw and deSilva, 1981; Soumillion and deWolf, 1981).

Table III. Photolysis of Predioxin 1 in Acetone (4 h)

compound	yield, %[a]	quantum yield[b]
15, pentachlorobenzene	5.5	0.0046
21, 2,3,4,5-tetrachlorophenol	3.4	0.0028
16, pentachlorophenol	8.2	0.0070
23a, hexachlorodibenzodioxin (isomer A)	19.6	0.0163
23b, hexachlorodibenzodioxin (isomer B)	4.6	0.0039
19, heptachloro-2-phenoxyphenol	1.0	0.00074
24, heptachlorodibenzodioxin	6.6	0.0055
26, heptachlorodibenzofuran	1.3	0.0009
25, heptachlorodibenzodioxin	5.0	0.0042
22, octachloro-2-phenoxyphenol	3.0	0.0025
27, octachlorodibenzodioxin	31.6	0.0264
1, predioxin	17.8	

[a] Mole percent, unnormalized. [b] Quantum yields were determined with cyclopentanone as the actinometer.

Table IV. Photolysis of Predioxin in Cyclohexane at 300 nm with *m*-Methoxyacetophenone as Sensitizer (6 h)

compound	yield, %[a]	$\Phi \times 10^3$ [b]
15, pentachlorobenzene	1.4 ± 0.16	0.74 ± 0.038
16, pentachlorophenol	29.0 ± 2.73	16.93 ± 1.67
18, cyclohexyltetrachlorophenol	0.9 ± 0.65	0.5 ± 0.37
19, heptachloro-2-phenoxyphenol	1.9 ± 1.9	1.65 ± 0.85
24, heptachlorodibenzodioxin	5.1 ± 0.29	2.99 ± 0.18
26, hydroxyheptachlorodibenzofuran	2.9 ± 0.20	1.7 ± 0.18
20a, octachloro-2-phenoxyphenol	13.8 ± 0.45	7.9 ± 0.99
20b, octachloro-2-phenoxyphenol (isomer)	5.9 ± 0.20	3.48 ± 0.35
22, octachloro-2-phenoxyphenol (isomer)	1.1 ± 0.16	0.63 ± 0.09
27, octachlorodibenzodioxin	13.2 ± 1.03	7.75 ± 0.74
1, predioxin	33.9 ± 2.74	

[a] Average of three runs. The yields reported are mole percent and unnormalized. [b] Quantum yields. These were determined by using cyclopentanone-pentenal actinometry.

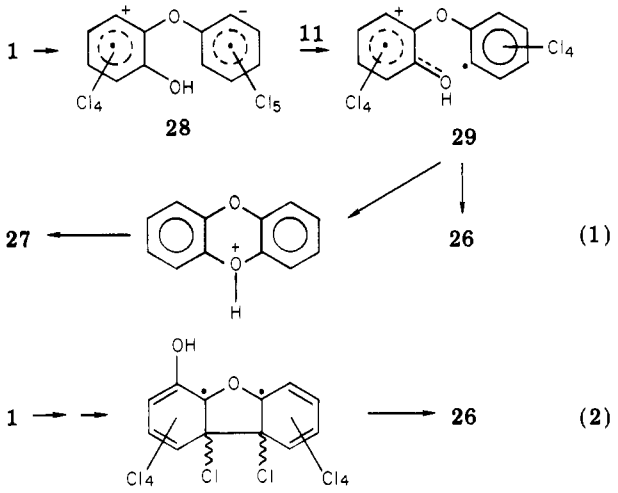
Table V. Photolyses of Predioxin in the Presence and Absence of Triethylamine (1 h, λ = 300 nm)

		acetone,[a] %	acetone containing triethylamine,[b] %
ether cleavage products:	16	2.1	3.0
	21		1.0
dechlorinated predioxin 1:	20a		11.0
	20b		6.5
dechlorinated dioxins:	23a	2.9	4.6
	23b		0.2
	24	5.1	3.6
	25	2.5	
octachlorodibenzodioxin:	27	5.6	20.8

[a] 7.056×10^{-3} M predioxin 1. [b] 7.056×10^{-3} M predioxin 1 in acetone with 8.61×10^{-2} M triethylamine.

To test the susceptibility of predioxin 1 to electron transfer, irradiation in acetone with and without triethylamine was investigated (Table V).

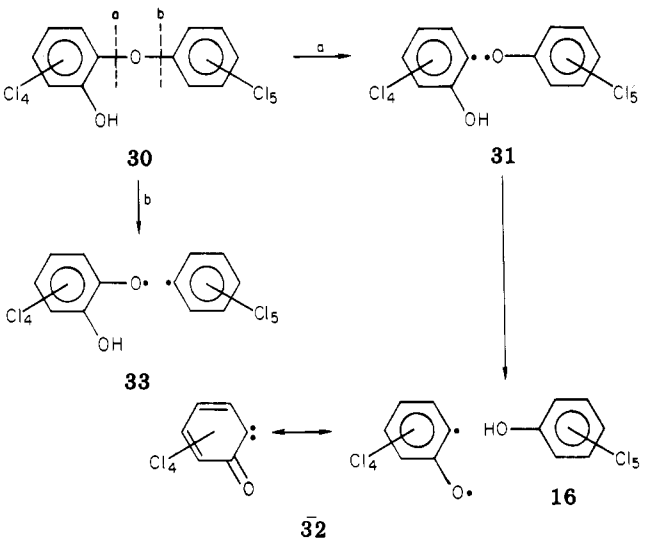
It is clear that cyclization to dioxin 27 is enhanced in the presence of an electron-transfer agent such as triethylamine. This reinforces the suggestion that a radical anion intermediate is the precursor for C–Cl bond cleavage and cyclization. Such an intermediate (28) might very well be produced in the absence of triethylamine in an intramolecular transfer (Okajima et al., 1977; Soumillion and deWolf, 1981; Todesco et al., 1981) which could expel a chloride ion to form cation diradical 29. Interaction with the odd electron density on the hydroxyl group would produce the conjugate acid of key photoproduct octachlorodibenzodioxin 27 (eq 1). Alternatively, the cation



dichloro 26

diradical could cyclize through interaction of the localized radical center in the right-side ring with the odd electron density on the ortho carbon of the left-side ring, which would lead (with loss of Cl^+) to hydroxyheptachlorodibenzofuran 26. An alternative pathway is brought into focus by considering the recent work of Grellman et al. (1981) on the photochemical cyclization of *N*-methyldiphenylamine which raises the interesting prospect that electrocyclic ring closure of triplet 1 might produce triplet dichloro 26, which could conceivably decay to ground-state singlet dichloro 26, which might (a) extrude molecular chlorine or (b) undergo a disproportionation process via chlorine atom transfers (eq 2).

The lack of cyclization in the direct irradiation suggests that intersystem crossing to the triplet state is unimportant and thus there is adequate energy for C–O and probably C–Cl bond homolysis in the precursor singlet state for ether cleavage and reductive dechlorination. The ether bonds are both strengthened and weakened, relative to aliphatic counterparts, by resonance, and, when the group equivalent method of Benson (1976) and data of Egger and Cocks (1973) are used, the dissociation energies of these bonds should be 78 kcal/mol or less, while the 94.5 kcal/mol bond energy of the aryl C–Cl bond would be reduced by relief of two ortho Cl–Cl interactions (4.4 kcal/mol) to bring the energy requirement very close to the O–O band, which appears to correspond to an excitation level of approximately 92 kcal/mol. The ether cleavage process occurs as a consequence of fission at bonds a and b (30), with no clear cut regioselectivity revealed. Fission at a leads to radical pair 31, which may diffuse apart or undergo hydrogen transfer within a solvent cage to generate pentachlorophenol and carbene 32, which might insert into solvent. Fission at b leads via radical pair



33 to tetrachlorocatechol, pentachlorobenzene, and the dechlorinated pentachlorobenzenes.

In the experiments where reductive dechlorination represents a substantial fraction of the product mixture (direct irradiation, acetone, triethylamine, and *m*-methoxyacetophenone) there appears to be a preference for chlorine replacement in the phenolic ring. For reactions proceeding via the triplet this may be due to facile ring closure to dioxin 27 when an ortho chlorine is lost from the pentachloro ring, whereas chlorine atom loss from the phenolic ring leads to reduction only. In the direct irradiation, cyclization does not compete; however due to the large fraction of ether cleavage and uncertainties concerning the regioselectivity for the ether cleavage for dechlorinated ethers derived from parent 1, a complete analysis depends upon additional experimentation.

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Registry No. 1, 35245-80-8; 17, 1198-55-6; 34, 17540-48-6; pentachlorophenol, 87-86-5; 3,4,5,6-tetrachloro-*o*-benzoquinone, 2435-53-2.

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Reaction of *p*-Hydroxycinnamic Acid Derivatives with Nitrite and Its Relevance to Nitrosamine Formation

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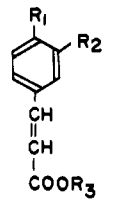
We studied loss of nitrite and inhibition of nitrosamine formation caused by naturally occurring *p*-hydroxycinnamic acid derivatives such as *p*-coumaric acid (I), ferulic acid (II), caffeic acid (III), and chlorogenic acid (IV). Compounds I, II, and III markedly reduced nitrite levels and inhibited nitrosamine formation. The potency of inhibition of nitrosamine formation was III > II > I > ascorbic acid ≫ cinnamic acid (V), and the order was almost the same as that of nitrite loss; III > II > I > IV > ascorbic acid > V. These effects are attributed to the chemical reactions of the phenolics with nitrite. From the reaction of monophenolics I and II with nitrite, many complicated products were isolated: product I(A), $C_8H_6N_2O_3$; I(B), $C_7H_6O_2$ (*p*-hydroxybenzaldehyde); I(D), $C_8H_5NO_3$; I(E), $C_8H_7NO_3$; II(A), $C_9H_8N_2O_4$; II(F), $C_9H_7NO_4$. Most of the reaction of nitrite with these monophenolics may be the addition reaction of nitrite to the olefinic group. Products I(A) and II(A) may be furoxan derivatives derived from dehydration of the nitroso–nitro or oxime–nitro compounds.

It has been well documented that nitrite reacts readily with secondary amines to produce carcinogenic nitrosamines (Sander and Seif, 1969; Druckrey et al., 1967). Nitrite may be present in some foodstuffs as an additive. It may be also yielded by salivary reduction from nitrate (Spiegelhalder et al., 1976). Certain compounds that are endogenous to foodstuffs or may be added as food additives exert effects on the nitrosamine formation from reaction of nitrite and secondary amines. Ascorbate (Mirvish et al., 1972), L-ascorbyl palmitate (Sen et al., 1976), acetals of ascorbate (Bharucha et al., 1980), unsaturated fatty acid (Kurechi and Kikugawa, 1979), soya products (Kurechi et al., 1981), and Japanese radish (Kurechi et al., 1980a) are known as inhibitors of the nitrosamine formation. Malondialdehyde (Kikugawa et al., 1980; Kurechi et al., 1980d) and alcohols (Kurechi et al., 1980c) are reported to be stimulatory on the nitrosamine formation. There are complicated effects, inhibition or stimulation, on the nitrosamine formation with the natural and synthetic phenolics. Polyphenols such as gallic acid and chlorogenic acid (Challis and Bartlett, 1975; Gray and Dugan, 1975; Nakamura and Kawabata, 1981; Sen et al., 1976; Walder et al., 1975; Yamada et al., 1978) and monophenolics such as α-tocopherol, sesamol, butylated hydroxyanisole, and cresol (Davies and McWeeny, 1977; Fiddler et al., 1978; Kurechi et al., 1979, 1980b; Pensabene et al., 1978; Walker et al., 1979) are inhibitory or stimulatory depending upon the conditions used.

In our previous paper (Kurechi et al., 1980a), it has been described that the inhibitory effect of Japanese radish on nitrosamine formation may be ascribed to unidentified unstable phenolics. This time, *p*-hydroxycinnamic acid derivatives which are widely distributed in plants and vegetables (Sosulski, 1979) were studied for nitrite loss, effects on nitrosamine formation, and reaction products between nitrite.

Chart I



I: *p*-coumaric acid; R_1=OH, R_2=R_3=H
II: ferulic acid; R_1=OH, R_2=OCH_3, R_3=H
III: caffeic acid; R_1=R_2=OH, R_3=H
IV: chlorogenic acid; R_1=R_2=OH, R_3=quinic acid
V: cinnamic aicd; R_1=R_2=R_3=H

MATERIALS AND METHODS

Materials. L-Ascrobic acid was the produce of Kanto Chemical Co., Inc. *p*-Coumaric acid (I), ferulic acid (II), caffeic acid (III), chlorogenic acid (IV), and *trans*-cinnamic acid (V) were the products of Tokyo Kasei Kogyo Co., Ltd. (see Chart I). Vanillin was purchased from Coso Chemical Co., Ltd. I, II, and V were dissolved at the indicated concentration by addition of 0.1 N or 1 N sodium hydroxide solution. Griess reagent was prepared by mixing an equal volume of 1.0% w/v sulfanilic acid in 30% glacial acetic acid and 1.0% w/v 1-naphtylamine in 30% glacial acetic acid just before use.

Analysis. Absorbances were measured with a Hitachi 101 spectrophotometer or a Shimadzu UV-200S double-

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