2-Amino-4-methyl-4-hydroxy-5-(2′,2′-dichlorovinyl)thiazoline Hydrochloride (6).—To a solution of 0.8 g (0.011 mol) of thiourea in 22 ml of ethanol was added 1.8 g (0.010 mol) of **2a** dropwise at 30–40°. The mixture was allowed to stand overnight. Removal of the solvent left a red-brown powder which on recrystallization from 80% ethanol gave 1.33 g (50%) of brown crystals. It showed one spot on tlc and became colorless after several recrystallizations from 80% C_2H_5OH: mp 192° dec: ir (Nujol) 3400 (OH), 2730 and 2600 (NH⁺), 1650 (C=C), and 1610 cm⁻¹ (NH₂).

Anal. Calcd for $C_6H_9Cl_3N_2OS$: C, 27.34; H, 3.44. Found: C, 27.49; H, 3.59.

3-Carbethoxy-4-(2′,2′-dichlorovinyl)-2,5-hexanedione (7).—Sodium (0.9 g, 0.039 g-atom) was dissolved in 13 ml of absolute ethanol. Ethyl acetoacetate (4.9 g, 0.038 mol) was added to this solution. At reflux temperature, 7 g (0.037 mol) of **2a** was dropped into the mixture and refluxing was continued for 1 hr. The sodium chloride precipitate was removed by filtration. After evaporation of the solvent and recovery of **2a** (1.5 g, 21%), an oil distilling at 133–135° (2.5 mm) was obtained: yield 1.2 g (11%); n²⁵D 1.4860; ir (liquid) 1730 (ester C=O), 1710 and 1684 (C=O), 1648 cm⁻¹ (C=C).

Anal. Calcd for $C_{11}H_{14}Cl_2O_4$: C, 46.99; H, 5.02. Found: C, 46.87; H, 4.77.

1,3,3-Trichloro-1-propenyl Methyl Ketone (10a).—A solution of 2.2 g (0.022 mol) of triethylamine in 3 ml of anhydrous ether was added dropwise to a solution of 4 g (0.021 mol) of **2a** in 5 ml of anhydrous ether cooled in an ice bath. After standing overnight it was filtrated to remove a trace of a brown precipitate. It was washed several times with water and dried with Na_2SO_4. Distillation gave a fraction of oil boiling at 90–91° (15 mm): yield 2.5 g (63%); n²⁹D 1.5049; ir (liquid) 1700 (C=O), and 1615 cm⁻¹ (C=C); uv max (cyclohexane) 239 mμ (ε 9720), 322 (39); nmr (CDCl₃) τ 2.94 (d, 1), 3.44 (d, 1), and 7.51 (s, 3).

Anal. Calcd for $C_5H_5Cl_3O$: C, 32.04; H, 2.69. Found: C, 32.02; H, 2.90.

1,3,3-Trichloro-1-propenyl Phenyl Ketone (10b).—A solution of 3 g (0.012 mol) of **2b** in 5 ml of ether was added with ice cooling to 3.7 g (0.037 mol) of **8** dissolved in 10 ml of anhydrous ether. The reaction mixture was kept cold for 30 min and then washed thoroughly with water. Removal of the solvent left a yellow liquid which on distillation gave 1.5 g (50%) of a yellow oil, bp 128–131° (2 mm). Microanalyses and spectral measurements were performed on samples collected by column chromatography (silica gel, hexane): n²⁴D 1.5768; ir (liquid) 1670 (C=O), 1618 (C=C), and 1595 cm⁻¹ (benzene C=C).

Anal. Calcd for $C_{10}H_7Cl_3O$: C, 48.13; H, 2.83. Found: C, 47.91; H, 2.75.

Addition Product of Diethylamine with 2b (12).—To a solution of diethylamine (1.1 g, 0.015 mol) in 2 ml of anhydrous ether, **2b** (1.0 g, 0.004 mol) dissolved in 2 ml of ether was added dropwise with ice cooling. A brown precipitate was separated immediately. It was gathered by filtration and washed thoroughly with anhydrous ether on filter paper and air-dried, giving 0.8 g (62%) of the crude product: mp 50° dec; ir (Nujol) 2480 and 2350 (NH⁺), 1700 (C=O, very weak), 1640 (C=C), and 1610 cm⁻¹ (benzene C=C). Because of rapid decomposition this product could not be purified for analysis, and so its physical constants may be in doubt.

Shift of ir absorption bands in C=O region with time is graphed on Figure 1 in the text.

It is insoluble in water, acetone, tetrahydrofuran, and ether, but soluble in benzene and chloroform, and very soluble in ethanol.

A Novel Reaction between Benzil and Certain
Nucleophilic Agents in N,N-Dimethylformamide[1]

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Benzil reacts with certain nucleophiles (phenoxide, *t*-butoxide, and hydroxide) in N,N-dimethylformamide to yield, in each case, benzoin benzoate (3) and the corresponding benzoylated nucleophile. *p*-Methoxybenzil reacts with sodium phenoxide to form *p*-methoxybenzoin anisate (5) and phenyl benzoate.

Perhaps the best known reaction of benzil with a nucleophile is that with hydroxide ion in which rearrangement occurs giving the conjugate base of benzilic acid.[2] Alkoxides are less successful in effecting the corresponding benzilic ester rearrangement except for those which have little or no tendency to transfer hydride ion. Thus, *t*-butoxide ion and methoxide ion react with benzil in alcoholic or benzene solution to yield the corresponding benzilic ester, whereas alkoxides containing more labile α hydrogens (*e.g.*, ethoxide and isopropoxide) lead to reduction products.[3] It is reported that the reaction between benzil and *t*-butoxide ion in diethyl ether results in the formation of benzilic acid.[4] Phenoxide ion fails to react with benzil in alcoholic or benzene solution, presumably owing to insufficient basicity on the part of the nucleophile.[4,5]

Phenoxide ion and benzil are likewise unreactive in

dimethyl sulfoxide (DMSO) at room temperature. A reaction occurs at higher temperatures, although the products obtained do not incorporate phenoxide.[6,7] Phenoxide ion functions as a base to generate dimsyl ion, which then reacts with benzil to form 3-benzoyl-2, 4,5-triphenylfuran (1), *cis*-α,β-dibenzoylstyrene (2), benzoic acid, and benzilic acid.
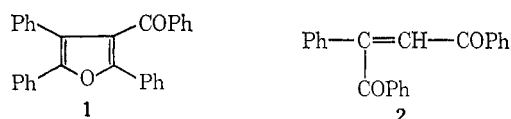

The present investigation was initiated to further confirm the necessity of DMSO to the formation of the products in the above reaction. In this respect the behavior of phenoxide ion toward benzil has been observed in a number of solvents. In the ethereal solvents, dimethoxyethane and diglyme, no reaction is en-

(1) Taken in part from the M.S. Thesis of J. D. Cheng.
(2) S. Selman and J. F. Eastham, *Quart. Rev.* (London), **14**, 221 (1960).
(3) W. von E. Doering and R. S. Urban, *J. Amer. Chem. Soc.*, **78**, 5938 (1956).
(4) G. A. Swan, *J. Chem. Soc.*, 1408 (1948).
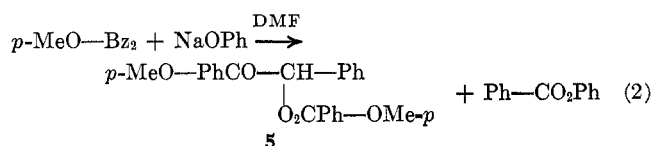(5) F. H. Westheimer, *J. Amer. Chem. Soc.*, **58**, 2209 (1936).

(6) J. C. Trisler, C. S. Aaron, J. L. Frye, and J. Y. Park, *J. Org. Chem.*, **33**, 1077 (1968).
(7) J. C. Trisler, J. K. Doty, and J. M. Robinson, *ibid.*, **34**, 3421 (1969).

countered even after extended periods at elevated temperatures. However, in N,N-dimethylformamide (DMF), a reaction occurs which results in the formation of benzoin benzoate (3) and phenyl benzoate (4) in near quantitative yields (eq 1).

$$2Bz_2 + PhO^- \longrightarrow Ph{-}CO{-}\underset{\underset{\underset{3}{OBz}}{|}}{CH}{-}Ph + Ph{-}CO_2{-}Ph \quad (1)$$
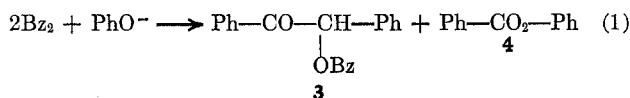
Unlike the reaction in DMSO where heating for extended periods is a necessary condition,[6] this reaction occurs very rapidly at or below room temperature. Stoichiometry was established by the fact that maximum yields ($\geq 90\%$) are obtained at a benzil–sodium phenoxide mol ratio of $\leq 2:1$ (yields based on benzil). Also, uv measurements have demonstrated that with the employment of a 4:1 mol ratio of benzil–sodium phenoxide, one-half the benzil remains after complete reaction.

The reaction of p-methoxybenzil with sodium phenoxide in DMF results in the formation of p-methoxybenzoin anisate (5) and phenyl benzoate (eq 2) although

$$p\text{-MeO}{-}Bz_2 + NaOPh \xrightarrow{\text{DMF}}$$
$$\underset{\underset{5}{O_2CPh{-}OMe\text{-}p}}{\overset{}{p\text{-MeO}{-}PhCO{-}\underset{|}{CH}{-}Ph}} + Ph{-}CO_2Ph \quad (2)$$

the reaction appears slower and the yields are somewhat lower. The mechanistic significance of the directional influence by the p-methoxyl group is under investigation and will be the subject of a future report.

An explanation of these data invoking a solvent effect where the nucleophilicity of phenoxide ion is greatly enhanced in DMF[8] is untenable since similar results would then be predicted in DMSO where the reaction fails to occur.[6] Thus, it is indicated that the role of DMF is more subtle than a bulk medium effect. Argument for a specific solvent effect is strengthened by the observation that the reaction occurs with no decrease in yield in a DMSO solution containing 22% DMF.

Should benzil react directly with an "alkoxide" type reagent, the expected product is that resulting from a benzilic ester[3] (or acid[2]) rearrangement. However, instead of rearrangement (of the above-mentioned type), cleavage of the central C–C bond in one benzil molecule has occurred while the other benzil carbon skeleton remains intact. These considerations led us to investigate whether reactions between benzil and certain other nucleophiles are similarly influenced by DMF.

In this respect a reaction has been observed between benzil and sodium t-butoxide in DMF to form 3 and t-butyl benzoate (6) (eq 3). The yields have generally

$$2Bz_2 + t\text{-BuO}^- \xrightarrow[25°]{\text{DMF}} 3 + Ph{-}CO_2{-}t\text{-Bu} \quad (3)$$
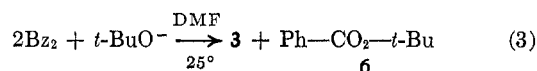
been around 50%. These results are of special interest since in other solvent systems different products are encountered; benzilic acid forms in ether[4] while t-butyl benzilate is the product in benzene or t-butyl alcohol.[3]

A genuine test of the "DMF effect" should be provided by the reaction between benzil and hydroxide ion.

That these reactants undergo the benzilic acid rearrangement under a variety of conditions is well documented.[2] The results of the reaction in DMF are given in Table I.

TABLE I
REACTION OF BENZIL WITH SODIUM HYDROXIDE IN DMF

Temp, °C	Yield of 3, %[a]	Yield of PhCO₂H, %[a]	Yield of Ph₂COHCO₂H, %[a]
−13	49	51	5
0	35	48	14
34	7	15	41

[a] Percentage yields are based on Bz₂ employed in a 2:1 mol ratio with sodium hydroxide.

That both the benzilic acid rearrangement and the reaction leading to 3 and benzoic acid have occurred is evident from a consideration of the data. Furthermore, it is apparent that a lowering of temperature causes a greater retardation in the rate of the rearrangement reaction. It is also observed that at the lowest reaction temperature, the quantities of 3 and benzoic acid are essentially the same, whereas at higher temperatures the ratio is decreased. This effect probably reflects the saponification of 3 at the higher temperatures. Indeed 3 is saponified with hydroxide in DMF at 0° to roughly the extent predicted from Table I.

The nature and extent of DMF involvement in this unique reaction of benzil and nucleophile is uncertain at the present time. However, it is interesting to speculate that the attack on benzil is nucleophilic in nature and that an alternate path to those "alkoxide"–benzil reactions previously established becomes possible in DMF. Furthermore, the influence of DMF must accommodate the attack of the weaker nucleophile, phenoxide ion, which is in general nonreactive toward the substrate in other solvent systems.

An extension of the present study to include other benzil–nucleophile reactions as well as an attempt to gain knowledge concerning the unique solvent effect is currently underway. This first report has defined a most unusual DMF alteration in the reaction path of certain benzil–nucleophile reactions. Also, for the first time a direct reaction between benzil and phenoxide ion has apparently been encountered.

Experimental Section[9]

Reaction of Benzil with Sodium Phenoxide in DMF.—Benzil (4.20 g, 20 mmol) was treated with sodium phenoxide[10] (1.16 g, 10 mmol) in 60 ml of DMF under a dry nitrogen atmosphere. After stirring at room temperature for 35 min, the mixture was poured into ice water, acidified, and extracted with ethyl ether. The ethereal solution was extracted with bicarbonate followed by aqueous sodium hydroxide (2.5%), washed with water, and dried over calcium chloride. The solution was then evaporated to a

(8) For a discussion of dipolar aprotic solvent effects on anionic reactions, see A. J. Parker, *Quart. Rev.* (London), **16**, 163 (1962).

(9) Melting points are uncorrected. The elemental analysis was carried out by Galbraith Laboratories, Knoxville, Tenn. Infrared spectra were obtained using the Nujol mull technique. The nmr spectra were determined in DCCl₃ at 60 Mc using Si(CH₃)₄ as an internal standard.

(10) N. Kornblum and A. P. Lurie, *J. Amer. Chem. Soc.*, **81**, 2705 (1959).

20–30-ml volume after which a small quantity of petroleum ether (bp 30–60°) was added to induce crystallization. The cooled system was filtered to yield 2.70 g of benzoin benzoate (3), mp 123–124° (lit.[11] mp 124–125°). The filtrate was evaporated and the residue was triturated with petroleum ether to obtain crude phenyl benzoate (4) which was recrystallized from petroleum ether to afford 0.81 g of the purified material, mp 67.5–69° (lit.[12] mp 69°). Product identification was realized in each case from mixture melting point and infrared data.

The combined filtrates were evaporated, and the residue was dissolved in 10 ml of benzene and introduced onto a deactivated column of alumina (50 g of Alcoa F-20 alumina and 2 ml of 10% aqueous acetic acid). An additional 0.83 g of 4, mp 67.5–69°, was eluted with petroleum ether (total yield of 4, 83%). Unreacted benzil (0.20 g) was eluted with 95:5 petroleum ether–ethyl ether. Elution with 80:20 petroleum ether–ethyl ether yielded 0.14 g of additional 3, mp 124–125° (from ether–petroleum ether). Total yield of 3 was 90%.

The bicarbonate wash from the initial ether extract was acidified and extracted with ether. The ethereal solution was washed with water, dried over calcium chloride, and evaporated to afford 0.18 g of acid residue. Sublimation resulted in 0.11 g of benzoic acid, mp 121–122°.

Very similar results were obtained where the reaction was conducted at −10° in DMF or at room temperature in a 22% DMF–DMSO solution.

Reaction of Benzil with Sodium t-Butoxide in DMF.—Sodium hydride[13] (1.17 g, 27 mmol) was treated with t-butyl alcohol (1.90 g, 25.7 mmol) in 70 ml of DMF. The system was stirred until the evolution of hydrogen gas had ceased. A solution of benzil (10.5 g, 50 mmol) in 30 ml of DMF was introduced under a dry nitrogen atmosphere. After stirring at room temperature for 1 hr, the contents were poured into ice water, acidified, and extracted with bicarbonate, washed with water, dried over calcium chloride, and evaporated to ∼20 ml. Dilution with petroleum ether followed by cooling in an ice bath resulted in the crystallization of a white solid. Filtration and recrystallization from ethanol afforded 3.96 g of 3, mp 123–124°. The ethanolic mother liquor was concentrated to yield 0.30 g of benzoin, mp 134–135°. Mixture melting point with an authentic sample in each case showed no depression.

The mother liquor from the initial filtration was evaporated and distilled to give 2.40 g (54% yield) of t-butyl benzoate (6), bp 81° (∼4 mm) [lit.[14] bp 213° dec and 94° (10 mm)]. The infrared spectrum was identical with that of an authentic sample.

The residue (from distillation) was dissolved in 10 ml of benzene and placed on a deactivated column of alumina (100 g of Alcoa F-20 alumina and 4 ml of 10% aqueous HOAc). A red oil was obtained by elution with petroleum ether which yielded 2.10 g of benzil on trituration with ethanol. Further elution with 97:3 petroleum ether–ethyl ether afforded 0.16 g of additional 3, mp 123–124° (total yield of 3, 51%).

The bicarbonate solution was acidified and extracted with ether. The ethereal layer was washed with water, dried over calcium chloride, and evaporated. The residue was sublimed to yield 0.77 g of benzoic acid, mp 119–121° and 0.25 g of benzilic acid, mp 148–149° (from ether–hexane).

Reaction of Benzil with Sodium Hydroxide in DMF.—Benzil was treated with sodium hydroxide in DMF at room temperature, 0 and −13°. The results are summarized in Table I. A typical procedure is given below.

Sodium hydroxide was generated by the reaction of water (0.10 g, 5.5 mmol) and sodium hydride[13] (0.25 g, 5.8 mmol) in 55 ml of DMF. After the evolution of hydrogen gas had ceased, the system was cooled in an ice bath to −13°. A solution of benzil (2.10 g, 10 mmol) in 5 ml of DMF was added to the cooled suspension. The resulting system was stirred vigorously for 1 hr, poured into ice water, acidified, and extracted with ether. The ethereal solution was extracted with bicarbonate, washed with

water, dried over calcium chloride, and evaporated to ∼10 ml. Petroleum ether was added and heat was applied until dissolution was complete after which the solution was cooled in an ice bath. After crystallization was complete, filtration afforded 0.67 g of 3, mp 123–124°. Mixture melting point with an authentic sample showed no depression.

The mother liquor was evaporated, the residue dissolved in 10 ml of benzene, and the resulting solution was placed on a deactivated column of alumina (50 g of Alcoa F-20 alumina and 1 ml of 10% aqueous acetic acid). Elution with petroleum ether resulted in the recovery of 0.74 g of benzil. Elution with 90:10 petroleum ether–ether afforded an additional 0.10 g of 3, mp 123–124° (total yield of 3, 49%).

The bicarbonate solution was acidified and extracted with ether. The ethereal solution was washed with water, dried over calcium chloride, and evaporated. Sublimation of the residue gave 0.31 g of benzoic acid, mp 121–122° (50.8% yield), and 0.11 g of benzilic acid, mp 148–149° (from ether–hexane).

Reaction of p-Methoxybenzil with Sodium Phenoxide in DMF.—Sodium phenoxide (0.30 g, 2.6 mmol) and p-methoxybenzil[15] (1.2 g, 5.0 mmol) were stirred in 30 ml of DMF at room temperature for 12 hr under a dry nitrogen atmosphere. The reaction mixture was worked up as previously described.

Sublimation of the acid portion afforded only a trace of p-methoxybenzoic (anisic) acid, mp 182–184° (ether–petroleum ether). Mixture melting point with an authentic sample showed no depression.

The neutral portion was obtained as an orange oil which was dissolved in 10 ml of benzene and introduced onto an alumina column (50 g of Alcoa F-20 alumina deactivated with 2 ml of 10% aqueous acetic acid). Elution with petroleum ether yielded 0.31 g (63% yield) of phenyl benzoate (4), mp 67–68° (from petroleum ether). Mixture melting point with an authentic sample showed no depression. Further elution with petroleum ether resulted in a trace of phenyl anisate, mp 72–73° (identified by mixture melting point). Elution with 87:13 solvent mixture afforded 0.15 g of p-methoxybenzil, mp 55–56°. Elution with ether produced a brown oil.

The oil was dissolved in a small quantity of ether, cooled in an ice bath, and diluted with petroleum ether. The container was scratched with a glass rod to induce crystallization. Filtration yielded 0.28 g (30% yield) of p-methoxybenzoin anisate (5), mp 91–92°. The infrared spectrum showed carbonyl absorption at 5.86 and 5.96 μ. The nmr spectrum showed two 3 H singlets (methoxyl) at δ 3.73 and 3.77, a 1 H singlet at δ 7.07 (methinyl), a 5 H multiplet at δ 7.2–7.7 (phenyl), and four 2 H doublets (J ≅ 9.0 cps) at δ 6.83, 6.97, 8.00, and 8.08 (two anisyl groups).

Anal. Calcd for $C_{23}H_{20}O_5$: C, 73.43; H, 5.32. Found: C, 73.25; H, 5.39.

The mother liquor was evaporated; the residue was dissolved in 5 ml of benzene and rechromatographed. Only a brown oil, 0.37 g, was recovered. Attempts to resolve the oil were unsuccessful. However, the infrared spectrum was identical with that of 5.

An authentic sample of p-methoxybenzoin anisate was prepared by acylating p-methoxybenzoin[15] with anisyl chloride under Schotten–Baumann conditions.[16] Mixture melting point with 5 showed no depression. Infrared and nmr spectra were identical for the two samples.

Registry No.—Benzil, 134-81-6; sodium phenoxide, 139-02-6; sodium t-butoxide, 865-48-5; sodium hydroxide, 1310-73-2; p-methoxybenzil, 22711-21-3; 5, 24866-71-5.

(11) N. Zinin, *Justus Liebigs Ann. Chem.*, **104**, 116 (1857).

(12) O. Dobner, *ibid.*, **210**, 246 (1881).

(13) Quantity of sodium hydride refers to a 56% by weight suspension in mineral oil. In each instance, mineral oil was removed by washing with petroleum ether.

(14) M. Pfannl, *Monatsh. Chem.*, **32**, 509 (1911).

(15) C. R. Kinney, *J. Amer. Chem. Soc.*, **51**, 1595 (1929).

(16) R. L. Shriner, R. C. Fuson, and D. Y. Curtin, "The Systematic Identification of Organic Compounds," 5th ed, Wiley, New York, N. Y., 1964, p 114.