The Chlorination of Alkyl Glyoxylate Phenylhydrazones and Triketone Phenylhydrazones

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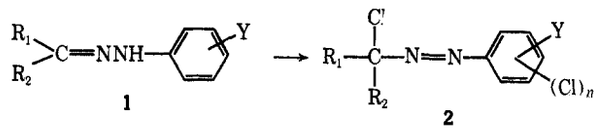
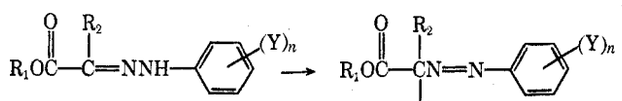
Alkyl glyoxylate phenylhydrazones (**3**, where R_2 = Cl, CH_3, or C_6H_5) reacted with chlorine or *tert*-butyl hypochlorite to give azo esters (**4**). Chlorination proceeds rapidly when the R_2 substituent is methyl or phenyl and relatively slowly when R_2 is chlorine. The azo esters are orange-colored compounds that decompose above 200° with evolution of nitrogen. Ethyl 2-chloro-2-[(*o*-methoxyphenyl)azo]propionate (**14a**) rearranged on heating in acetic acid to ethyl pyruvate 2-[(4-chloro-*o*-methoxyphenyl)hydrazone] (**13**). Methyl dichloro[(2,4,6-trichloro-*m*-tolyl)azo]acetate (**10**) decomposed in refluxing aqueous acetic acid to phosgene (2,4,6-trichloro-*m*-tolyl)-hydrazone (**15**). Reaction of 2,3,4-pentanetrione 3-(phenylhydrazone) with *tert*-butyl hypochlorite followed by methanolysis of the initially formed 3-chloro-3-phenylazo-2,4-pentanedione (**17**) afforded a new synthesis for pyruvoyl chloride 1-(phenylhydrazone).

We have recently prepared a variety of α-chlorophenylazo compounds (**2**) by chlorination of phenylhydrazones (**1**).[1] The preparation has wide utility provided that the substituent groups R_1, R_2, and Y are stable to the reaction conditions. Chlorination of the aromatic ring[2] often occurs before chlorination at the carbon–nitrogen double bond. When these competing chlorination reactions proceed at similar rates, mixtures of azo compounds, differing in the number or position of the ring chlorine atoms, are formed.[1] The reaction solvent and chlorinating agent can also be important in determining the structure of the reaction product.[3]



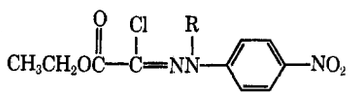
1 **2**

In this paper we describe the azo esters **4** obtained by reaction of alkyl glyoxylate phenylhydrazones (**3**, where R_2 is Cl, CH_3, or C_6H_5) with chlorine or *tert*-butyl hypochlorite. The pronounced effect of the substituent group R_2 on the rate of the chlorination reaction and some properties of the azo esters are also described.

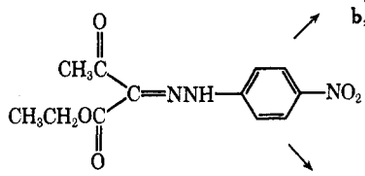


3 **4**

The intermediate alkyl chloroglyoxylate phenylhydrazones (**3**, R_2 = Cl) are conveniently prepared by chlorination of alkyl 2,3-dioxobutyrate 2-(phenylhydrazones).[3,4] For example, Chattaway and Ashworth[3] described the chlorination of ethyl 2,3-dioxobutyrate 2-[(*p*-nitrophenyl)hydrazone] (**5**) to **6a**. In the same study, conversion of **5** to the *N*-chloro compound **6b** was reported. We have resynthesized these compounds and have found from spectral studies that the compound



6a, R = H
b, R = Cl



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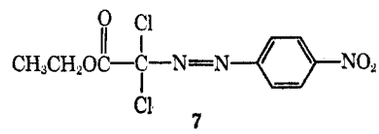

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reported as **6b** by Chattaway should be re-formulated as the isomeric ethyl dichloro[(*p*-nitrophenyl)azo]acetate (**7**). The product showed a low-intensity absorption at 398 mμ (ε 324) characteristic for the phenylazo structure[5] and a carbonyl absorption at 1755 cm^{-1} as expected for a nonconjugated, α-chlorinated ester.[6] The presence of strong ions corresponding to $O_2NC_6H_4^+$ and $O_2NC_6H_4N_2^+$ in the mass spectral fragmentation pattern of **7** is also consistent with the phenylazo structure.[1,7]

Compound **7** is the only azo ester of structure **4** reported in the literature. We have prepared related products by chlorination of other alkyl 2,3-dioxobutyrate 2-(phenylhydrazones). Unless strong electron-withdrawing substituents are present in the phenylhydrazone ring, the aromatic ring is chlorinated before the carbon–nitrogen double bond. For example, **8** reacted with excess chlorine in chloroform to give **10** in good yield (61%); at short reaction times **9** was the major product.

Treatment of methyl 2,3-dioxobutyrate 2-(*p*-tolylhydrazone) with chlorine gave methyl dichloro[(2,6-dichloro-*p*-tolyl)azo]acetate (*ca.* 25%). A second compound isolated in similar yield from this reaction was shown by mass spectral and elemental analysis to have

(1) Part of this work has been reported; see M. W. Moon, *J. Org. Chem.*, **37**, 383 (1971).

(2) J. E. Humphries, H. Humble, and R. Evans, *J. Chem. Soc.*, **127**, 1304 (1925).

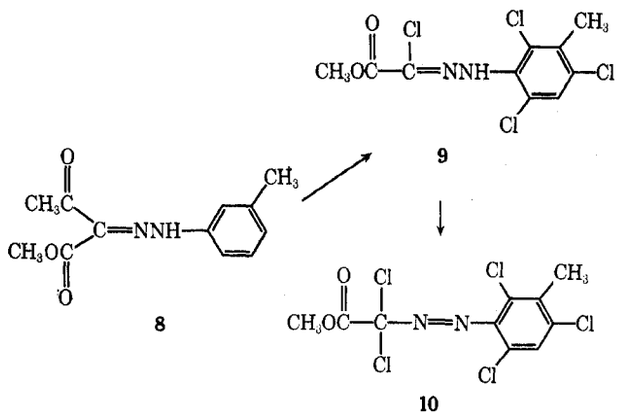
(3) F. D. Chattaway and D. R. Ashworth, *ibid.*, 1143 (1933); solvent effects in the chlorination of phenylhydrazones are described by these workers.

(4) An alternate synthesis for alkyl chloroglyoxylate phenylhydrazones involves reaction of an alkyl 2-chloroacetoacetate with a benzenediazonium chloride; see G. Favrel, *Bull. Soc. Chim. Fr.*, **31**, 150 (1904).

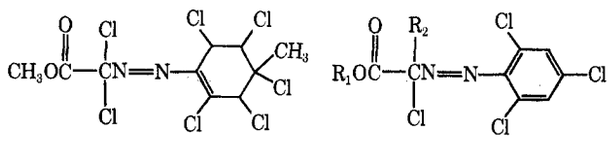
(5) A. E. Gillam and E. S. Stern, "An Introduction to Electronic Absorption Spectroscopy in Organic Chemistry," E. Arnold, London, 1958, p 127; A. Burawoy, *J. Chem. Soc.*, 1177 (1939).

(6) L. J. Bellamy, "The Infra-red Spectra of Complex Molecules," Methuen, London, 1959, p 179. Compound **6a** shows a carbonyl band at 1705 cm^{-1}.

(7) J. H. Bowie, G. E. Lewis, and R. G. Cooks, *J. Chem. Soc. B*, 621 (1967).



a molecular formula $C_{10}H_9Cl_7N_2O_2$. Structure **11** is proposed for this compound on the basis of the nmr, uv,



12a, $R_1 = CH_2CH_3$; $R_2 = CH_3$
b, $R_1 = CH_3$; $R_2 = C_6H_5$
c, $R_1 = CH_3$; $R_2 = Cl$
d, $R_1 = CH_2CH_3$; $R_2 = Cl$

and ir spectral data (λ_{max}^{hexane} 232 mμ, C=O absorption at 1750 cm^{-1}). We have found that chlorination of other *o*- and *p*-tolylhydrazones gives similar perchlorinated products[8] whose formation probably involves addition of chlorine at the aromatic ring carbon bearing the methyl substituent[9] followed by further chlorination of the resulting cyclohexadienone azine; chlorination of anilines in an inert solvent results in similar perchlorination of the aromatic ring.[10]

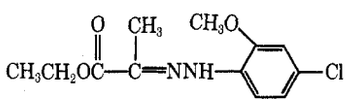
The intermediate hydrazones **3**, where R_2 is methyl or phenyl, were prepared by reaction of substituted phenylhydrazines with esters of pyruvic acid or phenylglyoxylic acid. The alkyl pyruvate phenylhydrazones were obtained as mixtures of the syn and anti isomers about the carbon–nitrogen double bond. While separation of the mixtures before chlorination was unnecessary,[11] the isomers were readily separated by chromatography on silica gel and the structures were assigned by nmr spectroscopy. The NH of the intramolecularly hydrogen bonded syn isomer absorbs near δ 12.0, while that of the anti isomer appears at about δ 8.0.[12a]

Alkyl pyruvate phenylhydrazones react with chlorine rapidly at the carbon–nitrogen double bond; chlorination in the aromatic ring occurs only when it is highly activated. The compounds may also be chlorinated using *tert*-butyl hypochlorite in an inert solvent. This reagent, a less powerful chlorinating agent than chlorine,[13] does not convert the alkyl chloroglyoxylate phenylhydrazones described earlier into azo esters.

Reaction of the (2,4,6-trichlorophenyl)hydrazones of ethyl pyruvate and methyl phenylglyoxylate with chlorine in chloroform gave **12a** and **12b**, respectively. The reactions were complete within 1 hr, whereas chlorination of methyl and ethyl chloroglyoxylate 2-[(2,4,6-trichlorophenyl)hydrazone] to give **12c** and **12d** under similar conditions was incomplete after 24 hr, illustrating the pronounced effect substituent R_2 has on the rate of chlorination of related phenylhydrazones of structure **3**.

Ethyl pyruvate 2-[(2,4,6-trichlorophenyl)hydrazone] reacted with trifluoromethyl hypofluorite to give ethyl 2-fluoro-2-[(2,4,6-trichlorophenyl)azo]propionate. The structure of this fluoroazo compound is supported by the nmr spectrum which shows the methyl group adjacent to the fluorine substituent as a doublet (J = 20 Hz).[12b]

Ethyl pyruvate 2-[(4-chloro-*o*-methoxyphenyl)-hydrazone] (**13**) gave **14a** when treated with *tert*-butyl hypochlorite. Chlorination of ethyl pyruvate 2-[(*o*-



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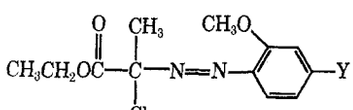
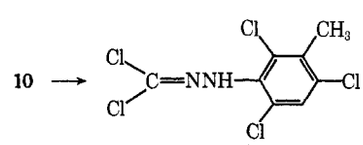


14a, Y = Cl
b, Y = H

methoxyphenyl)hydrazone] with the same reagent gave a mixture of **14a** (30%) and **14b** (70%) that was separated only by vpc. It was further characterized by vpc–mass spectrum and by identification of the hydrazones obtained on catalytic hydrogenation of the mixture.

The azo esters reported herein are orange-colored liquids or low-melting solids. They decompose with evolution of nitrogen when heated at temperatures above 200°. While most of the compounds are readily purified by chromatography on silica gel, **14a** and **14b** decomposed on attempted chromatography. The mixture of **14a** and **14b** rearranged slowly at room temperature, or more rapidly when heated in acetic acid with formation of ethyl pyruvate 2-[(4-chloro-*o*-methoxyphenyl)hydrazone] (**13**). As **13** was not obtained when **14a** was heated in acetic acid, we believe that it was formed by rearrangement of **14b**; related rearrangements of azo compounds have been reported.[14]

Compound **10** decomposed when heated in aqueous acetic acid to phosgene (2,4,6-trichloro-*m*-tolyl)hydrazone (**15**). This reaction may involve Japp–Klingemann displacement of the carbomethoxy group[15] or stepwise hydrolysis of **10** followed by decarboxylation of the resulting azo acid.



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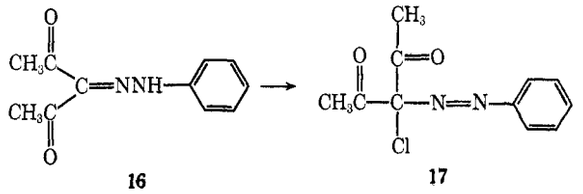
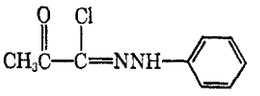
(8) M. W. Moon, unpublished results.
(9) M. S. Gibson, *J. Chem. Soc.*, 2270 (1962).
(10) W. J. Hickinbottom in "Chemistry of Carbon Compounds," Vol. IIIA, E. H. Rodd, Ed., Elsevier, Amsterdam, 1954, p 212.
(11) Both isomers of a given phenylhydrazone react with chlorine to give the same azo ester.
(12) (a) L. M. Jackman and S. Sternhell, "Applications of Nuclear Magnetic Resonance Spectroscopy in Organic Chemistry," Pergamon Press, Elmsford, N. Y., 1969, pp 103, 216; (b) p 348.
(13) M. Anbar and D. Ginsburg, *Chem. Rev.*, **54**, 925 (1954).
(14) The Chattaway–Adamson rearrangement involves an α-chloro phenylazo compound; see ref 1, footnote 3, and ref 9. Intramolecular rearrangements of α-nitro phenylazo compounds have also been reported: G. Ponzio, *Gazz. Chim. Ital.*, **39**, 535 (1909); **42**, 525 (1912).
(15) R. R. Phillips, *Org. React.*, **10**, 143 (1959).

We have found *tert*-butyl hypochlorite a valuable, mild reagent for the preparation of other α-chlorophenylazo compounds. This reagent reacted with 2,3,4-pentanetrione 3-(phenylhydrazone) (**16**) to give 3-chloro-3-phenylazo-2,4-pentanedione (**17**), identical



16 **17**



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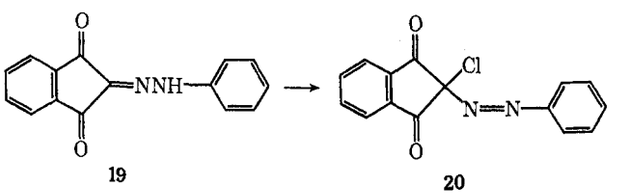
with the product obtained by reaction of 3-chloro-2,4-pentanedione with benzenediazonium chloride.[16] Compound **17** was converted in refluxing methanol to pyruvoyl chloride 1-(phenylhydrazone) (**18**).[15,17] This reaction sequence provides a convenient synthesis of **18** from **16**; reaction of **16** with limited amounts of chlorine cannot be controlled to give **18**, but gives instead pyruvoyl chloride 1-(*p*-chlorophenyl)hydrazone.

Reaction of 1,2,3-indantrione 2-(phenylhydrazone) (**19**) with chlorine and *tert*-butyl hypochlorite also gave different products. Chlorine converted **19** to 2,2-di-



19 **20**

chloro-1,3-indandione[18] and benzenediazonium chloride,[19] while *tert*-butyl hypochlorite reacted with **19** to give **20**.

Experimental Section[20]

The phenylhydrazone intermediates used in this study were prepared by standard procedures; spectral data are presented as well as analytical data for new compouuds.

Ethyl chloroglyoxylate 2-[(*p*-nitrophenyl)hydrazone] (**6a**) gave the following data: mp 193–195°; ir (Nujol) 1705 cm^{-1} (C=O); nmr [$(CD_3)_2NCDO$] δ 1.34 (s, 3, CH_3), 4.34 (q, 2, CH_2), 7.50 (d, 2, ArH), 8.15 (d, 2, ArH), and 11.14 (s, 1, NH); λ_{max}^{EtOH} 237 mμ (ε 7250), 284 (3750), and 365 (29,950); mass spectrum *m/e* for ^{35}Cl (rel intensity) 271 (100), 137 (15), and 136 (62).

Methyl chloroglyoxylate 2-[(2,4,6-trichlorophenyl)hydrazone] gave the following data: mp 82–84°; ir (Nujol) 1725 (C=O) and 1550 cm^{-1}; λ_{max}^{hexane} 296 mμ (ε 19,400).

Anal. Calcd for $C_9H_6Cl_4N_2O_2$: C, 34.21; H, 1.91; Cl, 44.88; N, 8.87. Found: C, 34.21; H, 2.13; Cl, 44.88; N, 9.00.

Ethyl pyruvate 2-[(2,4,6-trichlorophenyl)hydrazone] was obtained as a liquid isomer mixture and was readily separated by chromatography on silica gel into the syn and anti isomers.

Syn isomer: mp 51–53°; nmr ($CDCl_3$) δ 1.38 (t, 3, CH_3), 2.20 (s, 3, CH_3), 4.40 (q, 2, CH_2), 7.46 (s, 2, ArH), and 12.14 (s, 1, NH).

Anal. Calcd for $C_{11}H_{11}Cl_3N_2O_2$: C, 42.67; H, 3.58; Cl, 34.33; N, 9.05. Found: C, 42.58; H, 3.51; Cl, 34.22; N, 8.83.

Anti isomer: mp 64–68° nmr ($CDCl_3$) δ 1.35 (t, 3, CH_3), 2.20 (s, 3, CH_3), 4.40 (q, 2, CH_2), 7.48 (s, 2, ArH), and 7.75 (s, 1, NH).

Anal. Calcd for $C_{11}H_{11}Cl_3N_2O_2$: C, 42.67; H, 3.58; Cl, 34.33; N, 9.05. Found: C, 42.89; H, 3.71; Cl, 34.52; N, 8.96.

Methyl phenylglyoxylate 2-[(2,4,6-trichlorophenyl)hydrazone] was obtained as an isomer mixture: mp 111–123°; ir (Nujol) 1680 cm^{-1} (C=O); λ_{max}^{hexane} 238 mμ (ε 16,405) and 346 (18,590).

Anal. Calcd for $C_{15}H_{11}Cl_3N_2O_2$: C, 50.37; H, 3.10; Cl, 29.74; N, 7.84. Found: C, 50.36; H, 3.13; Cl, 29.87; N, 7.79.

Ethyl pyruvate 2-[(*o*-methoxyphenyl)hydrazone], mp 58–83°, was separated into the syn and anti isomers by chromatography on silica gel.

Syn isomer: mp 86–88°; ir (Nujol) 1680 cm^{-1} (C=O); nmr ($CDCl_3$) δ 1.30 (t, 3, CH_3), 2.14 (s, 3, CH_3), 3.82 (s, 3, OCH_3), 4.25 (q, 2, CH_2), 6.86 (m, 3, ArH), 7.50 (m, 1, ArH), and 12.0 (s, 1, NH); λ_{max}^{hexane} 239 mμ (ε 10, 500) and 360 (17,800).

Anal. Calcd for $C_{12}H_{16}N_2O_3$: C, 61.00; H, 6.83; N, 11.86. Found: C, 60.77; H, 6.91; N, 11.65.

Anti isomer: mp 72–74°; ir (Nujol) 1705 cm^{-1} (C=O); nmr ($CDCl_3$) δ 1.33 (t, 3, CH_3), 2.05 (s, 3, CH_3), 3.80 (s, 3, OCH_3), 4.26 (q, 2, CH_2), 6.86 (m, 3, ArH), 7.55 (m, 1, ArH), and 8.10 (s, 1, NH); λ_{max}^{hexane} 240 mμ (ε 10,200), 276 (7550), 285 (9150), and 322 (21,150).

Anal. Calcd for $C_{12}H_{16}N_2O_3$: C, 61.00; H, 6.83; N, 11.86. Found: C, 61.11; H, 6.83; N, 11.87.

Ethyl pyruvate 2-[(4-chloro-*o*-methoxyphenyl)hydrazone] (**13**), mixed isomers, was separated by chromatography into its syn and anti isomers.

Syn isomer: mp 109–111°; ir (Nujol) 1680 cm^{-1} (C=O); nmr ($CDCl_3$) δ 1.28 (t, 3, CH_3), 2.06 (s, 3, CH_3), 3.76 (s, 3, OCH_3), 4.18 (q, 2, CH_2), 11.90 (s, 1, NH) with aromatic hydrogens at 6.68 (d, 1, J = 2 Hz), 6.76 (d of d, 1, J = 2 and 8 Hz), and 7.30 (d, 1, J = 8 Hz); λ_{max}^{hexane} 243 mμ (ε 10,250) and 362 (20,200).

Anal. Calcd for $C_{12}H_{15}ClN_2O_3$: C, 53.24; H, 5.59; Cl, 13.10; N, 10.35. Found: C, 53.39; H, 5.86; Cl, 13.23; N, 10.75.

Anti isomer: mp 92–94°; ir (Nujol) 1680 cm^{-1} (C=O); nmr ($CDCl_3$) δ 1.34 (t, 3, CH_3), 2.04 (s, 3, CH_3), 3.78 (s, 3, OCH_3), 4.24 (q, 2, CH_2), 7.88 (s, 1, NH), with aromatic hydrogens at 6.72 (d, 1, J = 2 Hz), 6.81 (d of d, 1, J = 2 and 8 Hz), and 7.38 (d, 1, J = 8 Hz); λ_{max}^{hexane} 290 mμ (ε 12,600) and 327 (22,750).

Anal. Calcd for $C_{12}H_{15}ClN_2O_3$: C, 53.24; H, 5.59; Cl, 13.10; N, 10.35. Found: C, 53.47; H, 5.52; Cl, 13.08; N, 10.29.

Ethyl dichloro[(*p*-nitrophenyl)azo]acetate (**7**) was prepared as described by Chattaway[3] and purified before recrystallization by chromatography on silica gel using benzene as eluent: mp 64–66°; ir (Nujol) 1755 cm^{-1} (C=O); nmr ($CDCl_3$) δ 1.35 (t, 3, CH_3), 4.40 (q, 2, CH_2), 8.00 (d, 2, ArH), and 8.40 (d, 2, ArH); λ_{max}^{hexane} 278 mμ (ε 19,350) and 394 (324); mass spectrum *m/e* (rel intensity) 150 (59), 136 (5), and 122 (100).

Anal. Calcd for $C_{10}H_9Cl_2N_3O_4$: C, 39.23; H, 2.96; Cl, 23.17; N, 13.72. Found: C, 38.81; H, 2.88; Cl, 23.25; N, 13.78.

Methyl Chloroglyoxylate 2-[(2,4,6-trichloro-*m*-tolyl)hydrazone] (**9**).—Chlorine (10 ml, 0.22 mol) was added to a stirred solution of methyl 2,3-dioxobutyrate 2-(*m*-tolylhydrazone)[21] (5 g, 0.021 mol) in chloroform (50 ml) at −50°. The solution was allowed to warm to 0° and then immediately evaporated under reduced pressure. The solid obtained was recrystallized from Skellysolve B to give 3.0 g of **9**, mp 95–98°. Two recrystallizations from methanol gave the analytical sample: mp 96–98°; ir 1720

(16) W. Dieckmann and L. Platz, *Chem. Ber.*, **38**, 2986 (1905); the reaction product was extracted into Skellysolve B after 5 min to prevent hydrolysis to **18**.

(17) Alternate syntheses of pyruvoyl chloride phenylhydrazones have been described by (a) C. Bülow and P. Neber, *ibid.*, **46**, 2370 (1913); (b) G. Favrel, *Bull. Soc., Chim. Fr.*, **41**, 1494 (1927); (c) R. Huisgen and H. J. Koch, *Justus Liebigs Ann. Chem.*, **591**, 200 (1955).

(18) Identical with a sample prepared by the method of S. Ruhemann, *J. Chem. Soc.*, **97**, 2025 (1910).

(19) The formation of diazonium salts when phenylhydrazones are chlorinated in ethanol has been reported: C. Bülow, *Chem. Ber.*, **51**, 399 (1918).

(20) The mass spectra of solid products were recorded at 70 eV on an Atlas CH4 spectrometer; mass spectra of liquid products were recorded at 70 eV on an LKB 9000A gas chromatograph–mass spectrometer using a column of 1% QF-1 (2 ft × 3 mm i.d.) on 100–120 mesh Gas-Chrom Q maintained at 125°. Other analytical and chlorination procedures are described in ref 1.

(21) H. G. Garg and S. S. Joshi, *J. Indian Chem. Soc.*, **37**, 626 (1960).

cm^{-1} (C=O); nmr δ 2.46 (s, 3, CH_3), 3.91 (s, 3, CH_3O), 7.42 (s, 1, ArH), and 8.27 (s, 1, NH); λ_{max}^{hexane} 295 mμ (ϵ 20,090).

Anal. Calcd for $C_{10}H_8Cl_4N_2O_2$: C, 36.39; H, 2.44; Cl, 42.98; N, 8.49. Found: C, 36.47; H, 2.56; Cl, 43.14; N, 8.32.

Methyl Dichloro[(2,4,6-trichloro-*m*-tolyl)azo]acetate (10).—A stirred solution of methyl 2,3-dioxobutyrate 2-(*m*-tolylhydrazone)[21] (100 g, 0.43 mol) in chloroform (400 ml) at −40° was treated with chlorine (200 ml, 4.3 mol). The solution was stirred at 10° for 18 hr and was then evaporated to give 167 g of oil; tlc analysis indicated that the reaction was complete after *ca.* 2 hr. A portion (100 g) of the product was crystallized from methanol and gave 57 g of **10**, mp 42–45°. The analytical sample was recrystallized from petroleum ether (bp 30–60°): mp 44–46°; ir 1765 cm^{-1} (C=O); nmr ($CDCl_3$) δ 2.47 (s, 3, CH_3), 3.96 (s, 3, OCH_3), and 7.42 (s, 1, ArH); λ_{max}^{hexane} 256 mμ (ϵ 5360), 291 (5360), and 408 (429).

Anal. Calcd for $C_{10}H_7Cl_5N_2O_2$: C, 32.95; H, 1.94; Cl, 48.64; N, 7.69. Found: C, 33.21; H, 2.00; Cl, 48.09; N, 7.77.

Chlorination of Methyl 2,3-Dioxobutyrate 2-(*p*-Tolylhydrazone).—Chlorine (100 ml, 2.15 mol) was added at −40° to a stirred solution of methyl 2,3-dioxobutyrate 2-(*p*-tolylhydrazone)[21] (60 g, 0.255 mol) in chloroform (500 ml). The solution was stirred at room temperature for 18 hr and was then evaporated. The residual oil was dissolved in benzene–Skellysolve B (1:1) and chromatographed on silica gel. Methyl dichloro[(2,6-dichloro-*p*-tolyl)azo]acetate (10.2 g) was the first (yellow) band eluted from the column. This was crystallized from methanol and recrystallized from petroleum ether to give the analytical sample: mp 48–51°; ir (Nujol) 1770 cm^{-1} (C=O); nmr ($CDCl_3$) δ 2.36 (s, 3, CH_3), 3.95 (s, 3, OCH_3), and 7.25 (s, 2, ArH).

Anal. Calcd for $C_{10}H_8Cl_4N_2O_2$: C, 36.39; H, 2.44; Cl, 42.98; N, 8.48. Found: C, 36.39; H, 2.68; Cl, 42.69; N, 8.48.

Continued elution of the column gave 6.4 g of material that was discarded, followed by 17.5 g of material that was dissolved in hot methanol. On cooling 10.2 g of **11**, mp 114–117°, was obtained. Recrystallization from Skellysolve B gave the analytical sample: mp 116–118°; ir (Nujol) 1750 cm^{-1} (C=O); λ_{max}^{hexane} 232 mμ (ϵ 18,300) and 260 (shoulder, 2900); nmr ($CDCl_3$) δ 2.07 (s, 3, CH_3), 4.00 (s, 3, OCH_3), with cyclohexane ring protons at 4.70 (d, 1, J = 8 Hz), 4.98 (d, 1, J = 8 Hz), and 5.27 (s, 1); mass spectrum m/e for ^{35}Cl (rel intensity, number of chlorines in ion) 434 (10, 7), 399 (100, 6), and 363 (60, 5).

Anal. Calcd for $C_{10}H_9Cl_7N_2O_2$: C, 27.46; H, 2.07; Cl, 56.74; N, 6.40. Found: C, 27.37; H, 1.97; Cl, 56.17; N, 6.36.

Methyl Dichloro[(2,4,6-trichlorophenyl)azo]acetate (12c).—Chlorine (7 ml, 0.15 mol) was added to a stirred solution of methyl chloroglyoxylate 2-[(2,4,6-trichlorophenyl)hydrazone] (4.4 g, 0.014 mol) in chloroform (50 ml). After 18 hr the solvent was evaporated under reduced pressure and the residue was chromatographed on silica gel using a mixture of benzene and Skellysolve B as solvent to give 2.9 g of the yellow azo product as a liquid: ir (film) 1770 (C=O), 1550 and 1570 cm^{-1}; nmr ($CDCl_3$) δ 3.90 (s, 3, CH_3O) and 7.38 (s, 2, ArH); λ_{max}^{hexane} 255 mμ (shoulder, ϵ 6050), 282 (6300), and 410 (361); the major ions in the mass spectrum (^{35}Cl) were at m/e 207 and 179 (three chlorine pattern).

Anal. Calcd for $C_9H_5Cl_5N_2O_2$: C, 30.85; H, 1.44; Cl, 50.59; N, 7.99. Found: C, 30.79; H, 1.38; Cl, 50.89; N, 7.90.

Ethyl dichloro[(2,4,6-trichlorophenyl)azo]acetate (12d), prepared by the above method from ethyl chloroglyoxylate 2-[(2,4,6-trichlorophenyl)hydrazone],[22] was obtained as an orange oil: ir (film) 1760 (C=O), 1545 and 1570 cm^{-1}; nmr δ 1.37 (t, 3, CH_3), 4.43 (q, 2, CH_2), and 7.46 (s, 2, ArH).

Anal. Calcd for $C_{10}H_7Cl_5N_2O_2$: C, 32.95; H, 1.94; Cl, 48.64; N, 7.69. Found: C, 33.42; H, 1.87; Cl, 48.06; N, 7.99.

Ethyl 2-Chloro-2-[(2,4,6-trichlorophenyl)azo]propionate (12a).—Chlorine (5 ml, 0.11 mol) was added at −10° to a stirred solution of ethyl pyruvate 2-[(2,4,6-trichlorophenyl)hydrazone] (9.0 g mixed isomers, 0.029 mol) in carbon tetrachloride (100 ml). After addition of the chlorine was complete the mixture was evaporated under reduced pressure. The product was chromatographed on silica gel using benzene–Skellysolve B (1:4) as solvent to give 6.9 g of **12a** as a yellow oil. The analytical sample was further purified by distillation under reduced pressure: bp 155° (0.05 mm); ir 1750 (C=O), 1550, and 1570 cm^{-1}; nmr ($CDCl_3$) δ 1.34 (t, 3, CH_3), 2.21 (s, 3, CH_3), 4.40 (q, 2, CH_2), and 7.57 (s, 2, ArH); λ_{max}^{hexane} 240 mμ (ϵ 8710), 274 (4525), and 405 (290).

Anal. Calcd for $C_{11}H_{10}Cl_4N_2O_2$: C, 38.40; H, 2.93; Cl, 41.22; N, 8.14. Found: C, 38.34; H, 3.01; Cl, 41.33; N, 8.31.

Methyl Chlorophenyl[(2,4,6-trichlorophenyl)azo]acetate (12b).—Chlorine (5 ml, 0.11 mol) was added to a stirred solution of methyl phenylglyoxylate 2-[2,4,6-trichlorophenyl)hydrazone] (14 g, 0.04 mol) in chloroform (200 ml) at −30°. After 30 min the chloroform was removed and the residual oil was crystallized from Skellysolve B to give 12.45 g (81%) of **12b**, mp 56–58°. The analytical sample was recrystallized from Skellysolve B: mp 56–58°; ir ($CHCl_3$) 1750 (C=O), 1545, and 1565 cm^{-1}; nmr ($CDCl_3$) δ 3.80 (s, 3, OCH_3), 7.35 (m, 5, ArH), and 7.70 (m, 2, ArH); λ_{max}^{hexane} 240 mμ (shoulder, ϵ 10,130), 278 (6180), and 408 (355).

Anal. Calcd for $C_{15}H_{10}Cl_4N_2O_2$: C, 45.95; H, 2.57; Cl, 36.17; N, 7.15. Found: C, 45.83; H, 2.48; Cl, 36.33; N, 7.33.

Ethyl 2-Fluoro-2-[(2,4,6-trichlorophenyl)azo]propionate.—Excess gaseous trifluoromethyl hypofluorite was passed into a stirred solution of ethyl pyruvate 2-[(2,4,6-trichlorophenyl)-hydrazone] (6.0 g, 0.02 mol) in trichlorofluoromethane (100 ml) at −50°. After 30 min the solution was warmed to room temperature and evaporated. The residual oil was chromatographed on silica gel using benzene–Skellysolve B (1:3) as solvent. The fractions containing the orange azo compound were evaporated at 100° (10 mm) to give 2.1 g of ethyl 2-fluoro-2-[(2,4,6-trichlorophenyl)azo]propionate: ir (film) 1755 (C=O), 1545, and 1570 cm^{-1}; λ_{max}^{hexane} 242 mμ (ϵ 8100), 278 (4375), and 413 (285); nmr ($CDCl_3$) δ 1.28 (t, 3, CH_3), 1.90 (d, 3, J = 20 Hz, CH_3CF), 4.27 (q, 2, CH_2), and 7.35 (s, 2, ArH).

Anal. Calcd for $C_{11}H_{10}Cl_4FN_2O_2$: C, 40.33; H, 3.08; Cl, 32.47; F, 5.08; N, 8.55. Found: C, 40.49; H, 2.97; Cl, 32.70; F, 4.90; N, 8.73.

Ethyl 2-Chloro-2-[(4-chloro-*o*-methoxyphenyl)azo]propionate (14a).—To a solution of *syn*-ethyl pyruvate 2-[(4-chloro-*o*-methoxyphenyl)hydrazone] (3 g, 0.011 mol) in chloroform (25 ml was added 3 ml (0.025 mol) of *tert*-butyl hypochlorite. After 30 min the solution was evaporated at 60° (0.2 mm) to give 3.3 g of **14a** as a yellow oil: ir 1750 cm^{-1} (C=O); λ_{max}^{hexane} 232 mμ (ϵ 8850), 281 (9750), 328 (6700), and 400 (508); nmr ($CDCl_3$) δ 1.26 (t, 3, CH_3), 2.06 (s, 3, CH_3), 3.93 (s, 3, OCH_3), 4.23 (q, 2, CH_2) with aromatic protons at 6.86 (d of d, 1, J = 8 and 2 Hz), 7.00 (d, 1, J = 2 Hz), and 7.34 (d, 1, J = 8 Hz); vpc–mass spectrum, one peak at 125° (retention time 6.2 min); the mass spectrum was complex, but showed a strong ion at m/e 169 for the diazonium ion $C_7H_6ClN_2O^+$.

Anal. Calcd for $C_{12}H_{14}Cl_2N_2O_3$: C, 47.22; H, 4.62; Cl, 23.24; N, 9.18. Found: C, 47.24; H, 4.66; Cl, 23.54; N, 9.65.

Compound **14a** was also obtained when *anti*-ethyl pyruvate 2-[(4-chloro-*o*-methoxyphenyl)hydrazone] (1.0 g) was treated with *tert*-butyl hypochlorite (1.0 ml) in chloroform (10 ml). Evaporation of the chloroform gave an oil identical with **14a** by ir and nmr analysis.

Chlorination of Ethyl Pyruvate 2-[(*o*-Methoxyphenyl)hydrazone].—To a solution of ethyl pyruvate 2-[(*o*-methoxyphenyl)-hydrazone] (25 g of isomer mixture, 0.106 mol) in chloroform (250 ml) at 0° was added 25 ml (0.22 mol) of *tert*-butyl hypochlorite. After 30 min the solution was evaporated at 50° (0.2 mm) to give an orange oil: ir 1750 cm^{-1} (C=O); nmr ($CDCl_3$) δ 1.26 (t, 3, CH_3), 2.06 (s, 3, CH_3), 3.93 (s, 3, OCH_3), 4.23 (q, 2, CH_2), 6.08–7.00 (m, 2, ArH), and 7.15–7.45 (m, 1.7, ArH); vpc–mass spectrum, two peaks at 125° (retention times 3.2 and 6.2 min); the mass spectrum for the first peak showed a strong ion at m/e 135 for the diazonium ion $C_7H_7N_2O^+$; the mass spectrum for the second peak was identical with that obtained for **14a** above.

The above experiment was repeated on one-fifth the scale. The azo ester mixture obtained (5.3 g) was immediately dissolved in ethyl acetate (200 ml) and hydrogenated for 1 hr using 10% palladium on charcoal (250 mg) as catalyst. Tlc (250-μ silica gel GF plate) in benzene indicated the presence of four products with R_f values of 0.60, 0.50, 0.23, and 0.13. The bulk of the product was chromatographed on silica gel using benzene

(22) F. D. Chattaway and F. G. Daldy, *J. Chem. Soc.*, 2756 (1928).

as eluent. The first product (0.82 g) eluted from the column was the syn isomer of **13**. Continued elution gave 0.43 g of mixed isomers, followed by 1.35 g of *syn*-ethyl pyruvate 2-[(*o*-methoxyphenyl)hydrazone]. Elution of the column with ethyl acetate gave 1.80 g of a mixture of the anti isomers of **13** and ethyl pyruvate 2-[(*o*-methoxyphenylhydrazone]; the compounds were characterized by tlc, ir, and nmr.[23]

Formation of 13 from the Mixture of 14a and 14b.—The mixture of azo esters prepared above (30.9 g) was heated in acetic acid (150 ml) at 100° for 30 min. The acetic acid was removed under reduced pressure and the residual brown oil was chromatographed on silica gel using benzene as the eluent. The first product eluted from the column was *syn*-ethyl pyruvate 2-[(4-chloro-*o*-methoxyphenyl)hydrazone] (10.2 g); recrystallization from methanol gave 7.8 g, mp 108–112°.

Further elution of the column gave an additional 14 g of dark oil. Crystallization from ethyl acetate–Skellysolve B gave 3.4 g of *anti*-ethyl pyruvate 2-[(4-chloro-*o*-methoxyphenyl)hydrazone], mp 68–96°; recrystallization of the sample raised the melting point to 91–94°.

The syn and anti isomers of ethyl pyruvate 2-[(4-chloro-*o*-methoxyphenyl)hydrazone obtained in this reaction were identical with the samples previously prepared by tlc, nmr, melting point, and mixture melting point.

Action of Acetic Acid on 14a.—Compound **14a** (2 g) was heated at 100° for 2 hr in acetic acid. The acetic acid was removed by evaporation under reduced pressure; tlc and nmr analysis showed that the syn and anti isomers of ethyl pyruvate 2-[(4-chloro-*o*-methoxyphenyl)hydrazone] were not present in the reaction product.

Phosgene (2,4,6-Trichloro-*m*-tolyl)hydrazone (15).—Methyl dichloro[(2,4,6-trichloro-*m*-tolyl)azo]acetate (12 g, 0.03 mol) was heated under reflux in a mixture of acetic acid (125 ml) and water (25 ml) for 4 hr. The solution was cooled, diluted with water, and extracted with Skellysolve B (300 ml). The Skellysolve B was washed with water, dried, and evaporated to give an oil (5.5 g). This was dissolved in benzene–Skellysolve B (1:1) and was chromatographed on silica gel to give 4.4 g of phosgene (2,4,6-trichloro-*m*-tolyl)hydrazone. Recrystallization from petroleum ether gave the analytical sample: mp 39–41°; nmr ($CDCl_3$) δ 2.33 (s, 3, CH_3), 7.20 (s, 1, ArH), and 7.42 (s, 1, NH).

Anal. Calcd for $C_8H_5Cl_5N_2$: C, 31.36; H, 1.64; Cl, 57.86; N, 9.14. Found: C, 31.08; H, 1.61; Cl, 58.12; N, 8.96.

Pyruvoyl Chloride 1-(Phenylhydrazone).—A solution of 2,3,4-pentanetrione 3-(phenylhydrazone)[24] (102.4 g, 0.50 mol) was dissolved in chloroform (250 ml), cooled to 15°, and stirred. The temperature of the solution was maintained between 15 and 25° during the addition of *tert*-butyl hypochlorite (60 ml, 0.5 mol). After 30 min the solvent was evaporated to give **17** as an orange oil: ir 1730 cm^{-1} (C=O); nmr ($CDCl_3$) δ 2.34 (s, 6, CH_3), 7.30–7.60 (m, 3, ArH), and 7.70–7.95 (m, 2, ArH).

The product was dissolved in methanol (250 ml) and was heated to 60° for 15 min. On cooling to 0°, 71.3 g (73%) of pyruvoyl chloride 1-(phenylhydrazone) was obtained; mp 134–136°; ir 1665 cm^{-1} (C=O); nmr [$(CD_3)_2SO$] δ 2.48 (s, 3, CH_3), 6.90–7.60 (m, 5, ArH), and 8.50 (s, 1, NH).

Anal. Calcd for $C_9H_9ClN_2O$: C, 54.97; H, 4.61; Cl, 18.03; N, 14.25. Found: C, 54.96; H, 4.65; Cl, 17.90; N, 14.30.

Pyruvoyl Chloride 1-[(*p*-Chlorophenyl)hydrazone].—Chlorine (9.2 ml, 0.2 mol) was added to a stirred solution of 2,3,4-pentanetrione 3-(phenylhydrazone) (20.4 g, 0.1 mol) in chloroform (300 ml) at −50°. The solution was allowed to warm to room temperature and was evaporated after 30 min. The residual solid was recrystallized twice from ethyl acetate to give 6.1 g of pyruvoyl chloride 1-[(*p*-chlorophenyl)hydrazone], mp 169–172°. Recrystallization from ethyl acetate gave the analytical sample, mp 172–174°.

Anal. Calcd for $C_9H_8Cl_2N_2O$: C, 46.77; H, 3.49; Cl, 30.69; N, 12.13. Found: C, 47.07; H, 3.24; Cl, 31.05; N, 12.22.

Preparation of 17 from 3-Chloro-2,4-pentanedione.—Sodium nitrite (6.9 g, 0.1 mol) in water (30 ml) was added at 0° to a stirred mixture of aniline (9.3 g, 0.1 mol), concentrated hydrochloric acid (22 ml), and water (300 ml). Sodium acetate (13.6 g, 0.1 mol) was then added followed by 3-chloro-2,4-pentanedione (6.7 g, 0.05 mol). The resulting inhomogeneous solution was shaken vigorously for 6 min and was then extracted with Skellysolve B (500 ml). The Skellysolve B was washed with water (three 200-ml portions), dried over anhydrous sodium sulfate, and evaporated at 100° (10 mm). The brown oil thus obtained was identical by nmr and ir analysis with **17** prepared from 2,3,4-pentanetrione 3-(phenylhydrazone) and *tert*-butyl hypochlorite.

2-Chloro-2-phenylazo-1,3-indandione (20).—To a cooled (10°) solution of 1,2,3-indantrione 2-(phenylhydrazone)[25] (5 g, 0.02 mol) in chloroform (50 ml) was added 3.4 ml (0.028 mol) of *tert*-butyl hypochlorite. After 1 hr the solvent was removed at reduced pressure and methanol was added. The solid that precipitated was filtered off and recrystallized from ethyl acetate to give 2.5 g of **20**, mp 138–140°.

Anal. Calcd for $C_{15}H_9ClN_2O_2$: C, 63.28; H, 3.19; Cl, 12.46; N, 9.84. Found: C, 62.98; H, 3.16; Cl, 12.47; N, 9.60.

Chlorination of 1,2,3-Indantrione 2-(Phenylhydrazone) (20).—Chlorine (5 ml, 0.11 mol) was added to a stirred solution of **20** (12.5 g, 0.05 mol) in chloroform (200 ml) at −30°. The solution was allowed to warm to room temperature over 30 min and was then concentrated slightly to remove hydrogen chloride and chlorine by evaporation at reduced pressure (50 mm); a crystalline, water-soluble solid (benzenediazonium chloride) separated during the evaporation. The reaction solution was extracted with water (150 ml).

The aqueous solution was added to a stirred solution of 2,4-pentanedione (10 g), sodium hydroxide (4 g), and sodium acetate (26 g of trihydrate) in water (100 ml). A precipitate of 5.4 g of 2,3,4-pentanetrione 3-(phenylhydrazone), mp 82–85°, was obtained: nmr ($CDCl_3$) δ 2.40 (s, 3, CH_3), 2.52 (s, 3, CH_3), 7.0–7.4 (m, 5, ArH), and 14.65 (s, 1, NH). The product was identical with an authentic sample of **16**.

Evaporation of the chloroform gave 11.9 g of material. This was refluxed for 30 min in methanol[26] and cooled to give 5.6 g of 2,2-dichloro-1,3-indandione, mp 121–124°. Recrystallization from methanol gave the analytical sample, mp 124–126°.

Anal. Calcd for $C_9H_4Cl_2O_2$: C, 50.27; H, 1.87; Cl, 32.98. Found: C, 50.32; H, 2.08; Cl, 32.65.

Registry No.—**6a**, 27143-13-1; **7**, 32979-34-3; **9**, 32979-35-4; **10**, 32979-36-5; **11**, 32979-37-6; **12a**, 33020-72-3; **12b**, 32979-38-7; **12c**, 32979-39-8; **12d**, 32979-40-1; **13** isomer a, 32979-65-0; **13** isomer b, 32979-66-1; **14a**, 32974-72-4; **15**, 32974-73-5; **16**, 6134-57-2; **20**, 33020-73-4; methyl chloroglyoxylate 2-[(2,4,6-trichlorophenyl)hydrazone], 32974-75-7; ethyl pyruvate 2-[(2,4,6-trichlorophenyl)hydrazone] isomer a, 32979-67-2; ethyl pyruvate 2-[(2,4,6-trichlorophenyl)hydrazone] isomer b, 32979-68-3; methyl phenylglyoxylate 2-[(2,4,6-trichlorophenyl)hydrazone], 32974-76-8; ethyl pyruvate 2-[(*o*-methoxyphenyl)-hydrazone], 33020-74-5, 32979-69-4 (isomer a), 20538-15-2 (isomer b); methyl dichloro[(2,6-dichloro-*p*-tolyl)azo]acetate, 32974-77-9; ethyl 2-fluoro-2-[(2,4,6-trichlorophenyl)azo]propionate, 32974-78-0; pyruvoyl chloride 1-(phenylhydrazone), 18440-58-9; pyruvoyl chloride 1-[(*p*-chlorophenyl)hydrazone], 18247-78-4; 2,2-dichloro-1,3-indandione, 32974-80-4.

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(23) The syn and anti isomers of ethyl pyruvate 2-(5-chloro-*o*-methoxyphenyl)hydrazone, mp 105–107 and 119–121° respectively, were also synthesized; these compounds, which show an absorption at δ 7.45 (d, 1, J = 2 Hz, ArH) in the nmr ($CDCl_3$), were not present in the reduction mixture.

(24) C. Beyer and L. Claisen, *Chem. Ber.*, **21**, 1697 (1888).

(25) W. Wislicenus and F. Reitzenstein, *Justus Liebigs Ann. Chem.*, **277**, 362 (1893).

(26) Recrystallization of the product from ethyl acetate–Skellysolve B or methanol gave a product with a wide melting range. The methanol reflux was necessary to remove contaminants from the 2,2-dichloro-1,3-indandione.