methyl 1.9, 3-methyl 3.0, 4-methyl 1.3, 2,3-dimethyl 3.5, 2,4-dimethyl 2.6, 2,5-dimethyl > 8, 2,6-dimethyl- 1.4, 3,4-dimethyl 2.2, 3,5-dimethyl > 7, 2,4,6-trimethyl 1.0, 4-*tert*-butyl 0.8, 2,6-di-*tert*-butyl- 1.9, 2-hydroxy- > 5,3-hydroxy > 13, 4-hydroxy > 17, 2-chloro-, 1.3, 3-chloro-, 0.2, 4-chloro-, 0.2, 2-bromo-, 0.9, 2-iodo- 2.6, 2-nitro- 0.1; [ketones] acetone 0.4, methyl ethyl 0.2, methyl *n*-butyl 0.2, methyl *n*-amyl 0.2, methyl isopropyl 0.1, ethyl *tert*-butyl 0.02, diethyl 0.2, methyl cyclopropyl 0.07, dicyclopropyl 0.07, mesityl oxide 0.6, acetylacetone > 10, cyclopentanone 0.64, cyclohexanone 1.7, 2-methylcyclohexanone 0.9, 4-*tert*-butylcyclohexanone 1.6, cyclobutanone 0.02, cyclohexenone 0.3, and isophorone 0.2. At 25°, the following reaction times were found: 2-hydroxyphenol, 240 sec.; 3-hydroxyphenol, 780 sec.; acetylacetone, 420 sec., and cyclohexanone, 31,000 sec.

Halogenation with Copper(II). II. Unsaturated Ketones

Edward M. Kosower[1] and G.-S. Wu[2]

Department of Chemistry, The University of Wisconsin, Madison, Wisconsin

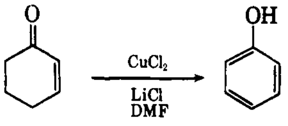
Received September 17, 1962

The halogenation procedure previously described[3] was applied to a number of unsaturated ketones. 2-Cyclohexenone and 3-methyl-2-cyclohexenone gave phenol and *m*-cresol, respectively. Isophorone yielded 3-chloromethyl-5,5-dimethyl-2-cyclohexenone and 6-chloro-3,5,5-trimethyl-2-cyclohexenone in about equal quantities along with a lesser quantity of some phenols. Mesityl oxide and isomesityl oxide form mixtures (*in different proportions*) of almost every possible monochlorinated product. Methyl vinyl ketone leads to 3-chloro-3-buten-2-one. The mechanisms for the halogenation reactions are discussed.

The procedure for halogenation with copper(II) halides[3] was applied to several simple acyclic and cyclic unsaturated ketones.[4]

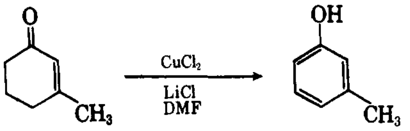
Results

Cyclic Ketones.—Treatment of 2-cyclohexenone with copper(II) chloride under the usual conditions for chlorination for four hours led to phenol in 65% yield. No organic product other than phenol could be observed when a shorter reaction time was used (equation 1).



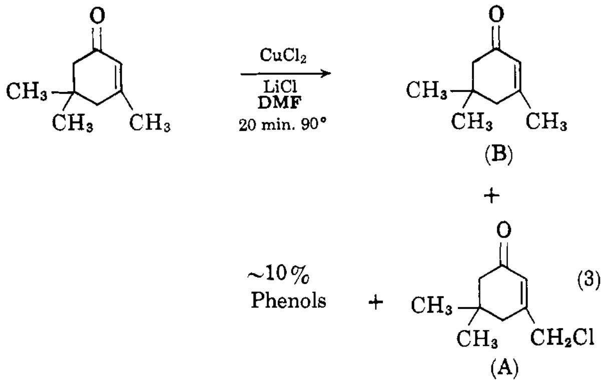
(1)

A parallel result was obtained with 3-methyl-2-cyclohexenone as the substrate (equation 2) and even very short reaction times did not lead to the detection of any chlorinated intermediates.



(2)

Isophorone is chlorinated rapidly by copper(II) chloride at 90–95°. The product mixture is easily isolated but rather difficult to separate into components due to the instability of the chloro ketones, especially when impure. Fractional distillation followed by chromatography on Florisil led to the isolation of two chloroketones (A) and (B) as well as three phenols (equation 3). Separation of pure components was made possible by gas chromatographic analysis, successful only under very carefully defined conditions.

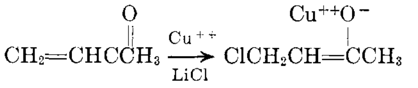


Chloro ketone (A) was identified as 3-chloromethyl-5,5-dimethyl-2-cyclohexenone by the following evidence. Elemental analysis corresponded perfectly to that expected for the chloro ketone. The carbonyl band in the infrared and both the n → π* and π → π*-transitions in the ultraviolet were almost identical in position to those of isophorone, indicating that the chlorine was distant from the carbonyl group. The n.m.r. spectrum, finally, indicated that a methyl group of isophorone had been converted to a chloromethyl group.

Chloro ketone (B) was isomeric with (A). However, the considerable shifts in (a) the carbonyl band of the infrared (1675 cm.$^{-1}$) from that of isophorone (1660 cm.$^{-1}$); (b) the n → π* transition (3218 Å. *vs.* 3367 Å. for isophorone); and (c) the π → π* transition (2429 Å. *vs.* 2253 Å.) suggested that the chlorine was located at the 6-position and that (B) was therefore 6-chloro-3,5,5-trimethyl-2-cyclohexenone. The n.m.r. spectrum was consistent with this formulation, especially in showing that an alkene hydrogen was present.

Three phenols present in the crude product were identified as 6-chloro-2,3,5-trimethylphenol, 2,3,5-trimethylphenol, and 2-chloro-3,4,5-trimethylphenol.

Acyclic Ketones.—The simplest α,β-unsaturated ketone, methyl vinyl ketone, was chlorinated to give 3-chloro-3-butenone, probably through the sequence of reactions shown in equations 4, 5, and 6. A related



$$CH_2{=}CH\overset{\overset{O}{\|}}{C}CH_3 \xrightarrow[LiCl]{Cu^{++}} ClCH_2CH{=}\overset{\overset{Cu^{++}O^-}{|}}{C}CH_3 \qquad (4)$$

---

[1] (a) Alfred P. Sloan Fellow; (b) to whom requests for reprints should be addressed at the Department of Chemistry, State University of New York, Stony Brook, N. Y.

[2] Taken in part from the Ph.D. thesis of G.-S. Wu, January, 1962.

[3] E. M. Kosower, W. J. Cole, G.-S. Wu, D. E. Cardy, and G. Meisters, *J. Org. Chem.*, **28**, 630 (1963).

[4] The authors are grateful to the Air Force Office of Scientific Research for support under contract AF 49 (638)-282.

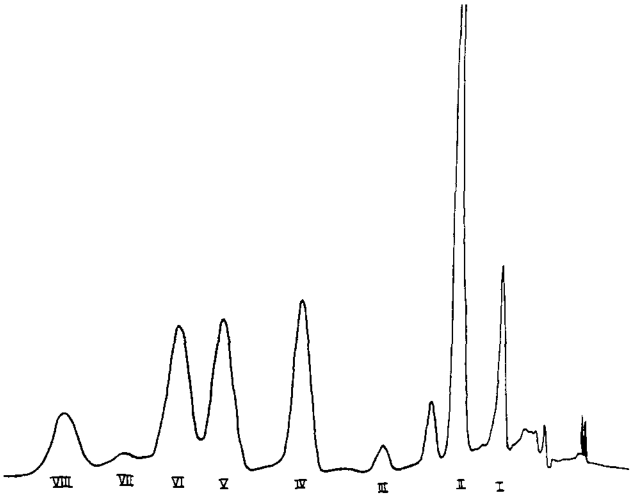
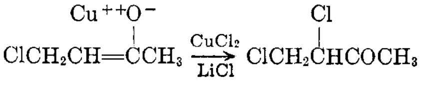
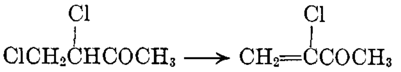


Fig. 1.—G.l.p.c. analysis of chlorination product of mesityl oxide. The peaks are I, isomesityl oxide; II, mesityl oxide; III, X; IV, A; V, B′; VI, B; VII, C′; VIII, C. The retention time for product D was too great to permit its inclusion in the figure.



$$\mathrm{ClCH_2CH{=}\overset{Cu^{++}O^-}{C}CH_3 \xrightarrow[LiCl]{CuCl_2} ClCH_2\overset{Cl}{C}HCOCH_3} \qquad (5)$$



$$\mathrm{ClCH_2\overset{Cl}{C}HCOCH_3 \longrightarrow CH_2{=}\overset{Cl}{C}COCH_3} \qquad (6)$$

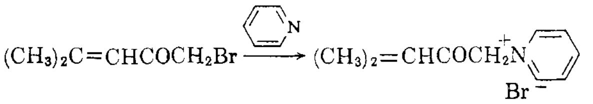
reaction, the conversion of α,β-unsaturated aldehydes to β-alkoxy-α-haloaldehydes (or acetals) with copper(II) halide in alcoholic media, has been reported by Castro.[5]

The 3-chloro-3-butenone was extremely unstable, even at 0°, and polymerized. It was obtained in pure form only with g.l.p.c. and in poor yield. Its structure was proven by its identity with authentic material, synthesized in 4% yield by the method of Petrov and Leporskaya.[6] The properties of the chloro ketone were quite different from those of chloromethyl vinyl ketone, prepared by the reaction of ethylene, chloroacetyl chloride, and aluminum chloride.[7] For example, the $\lambda_{\max}^{\text{isoöctane}}$ for the $\pi \rightarrow \pi^*$ transition of 3-chloro-3-butenone occurs at 2295 Å. (ϵ 9000) in comparison to 2140 Å. (ϵ 7800) for chloromethyl vinyl ketone and 2040 Å. (ϵ 8500) for methyl vinyl ketone.

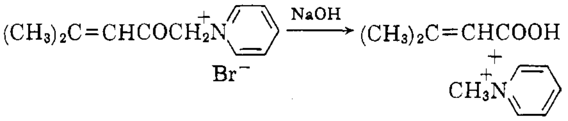
The length, inconvenience (starting material is chloroprene), and low yield of the previously reported synthesis[6] for 3-chloro-3-butenone suggest that the conversion reported in this paper would be a useful preparative method.

Mesityl Oxide and Isomesityl Oxide.—Buü-Hoi[8] has noted without detail that mesityl oxide reacts with *N*-bromosuccinimide in carbon tetrachloride to give a yellow lachrymatory liquid, b.p. 40–45°/1 mm. The unstable product, sensitive to light and air, was said to be 1-bromo-4-methyl-3-penten-2-one. Cole[9] has reported a 12% yield of the same bromo ketone (and/or its unconjugated isomer) as proven by the isolation of β,β-dimethylacrylic acid from basic cleavage of a pyridinium salt derived from the bromo ketone formed by the reaction of mesityl oxide and copper(II) bromide (equations 7, 8, and 9).

$$\mathrm{(CH_3)_2{=}CHCOCH_3 \xrightarrow[LiBr]{CuBr_2} (CH_3)_2C{=}CHCOCH_2Br + \ldots} \qquad (7)$$

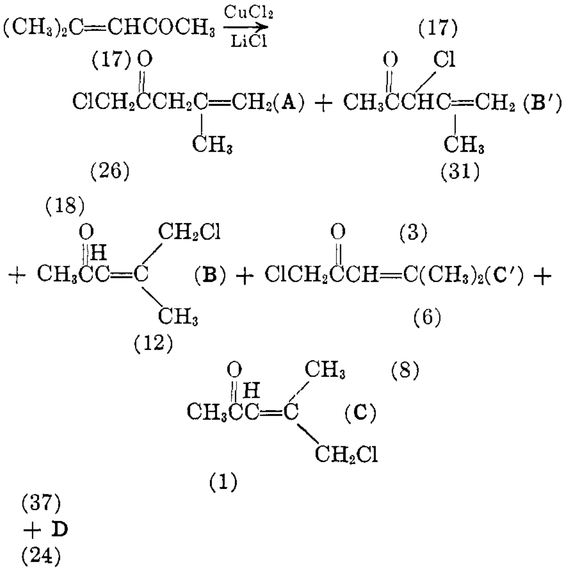


(8)



(9)

Chlorination of mesityl oxide led to a complex mixture, readily resolvable by g.l.p.c. (Fig. 1). Separation of reasonable quantities of single components proved to be tedious, requiring g.l.p.c. after careful fractional distillation. Isomesityl oxide (69% pure) gave a similar mixture of products, *in different proportions*. The structures assigned are shown in equation 10. Above the formulas are given the proportions (g.l.p.c.) from mesityl oxide, while below are shown those from isomesityl oxide.



(10)

Chloro ketones **B** and **C** are α,β-unsaturated ketones; apparently **C** is readily converted into **B**. They are therefore considered to be *cis–trans* isomers of which the more stable isomer has the chloromethyl group *trans* to the acetyl group. The decreased yields of **B** and **C** from isomesityl oxide are in agreement with their structures. Both **B** and **C** possess ultraviolet maxima in isoöctane at wave lengths appreciably longer than that for mesityl oxide [2400 Å. (**B**) and 2446 Å. (**C**) *vs.* 2304 Å.; 3337 Å. (**B**) and 3314 Å. (**C**) *vs.* 3284 Å.]. However, the infrared absorption which corresponds to that for a conjugated carbonyl group is almost the same in all three compounds($\bar{\nu}_{\mathrm{C=O}}$ 1678 cm.$^{-1}$ (**B**), 1686 cm.$^{-1}$ (**C**), and 1686 cm.$^{-1}$). The n.m.r. spectra of **B** and **C** were similar.

Chloro ketones **A** and **B′** could only be isolated by g.l.p.c. separation since they disappeared during fractional distillation. Both were saturated ketones $\bar{\nu}_{\mathrm{C=O}}$ 1709 cm.$^{-1}$ (**A**), 1718 cm.$^{-1}$ (**B′**); $\lambda_{\max}^{\text{isoöctane}}$ 2809 Å. (**A**), 2810 Å. (**B′**). The marked increase in the relative yield of **B′** from isomesityl oxide suggested

---

[5] C. E. Castro, *J. Org. Chem.*, **26**, 4183 (1961).

[6] A. A. Petrov and E. A. Leporskaya, *Zh. Obsch. Khim.*, **23**, 1034 (1953); *Chem. Abstr.*, **48**, 8181f (1954).

[7] J. R. Catch, D. E. Elliott, D. H. Hey, and E. R. H. Jones, *J. Chem. Soc.*, 272 (1948).

[8] Ng. Buü-Hoi, *Experientia*, **2**, 310 (1946).

[9] W. J. Cole, M.S. thesis, June, 1959.

TABLE I

CHLORINATION OF UNSATURATED KETONES WITH COPPER(II) CHLORIDE[a]

Substrate	Product (yield, %)	Identification
Cyclohexenone	Phenol (65)[b]	Infrared,[c] derivative, phys. properties
3-Methylcyclohexenone	*m*-Cresol (66)[b]	g.l.p.c.,[d] infrared
Isophorone	3-Chloromethyl-5,5-dimethyl-2-cyclohexenone (35)[b]	Infrared, ultraviolet,[e] anal., n.m.r.[f]
	6-Chloro-3,5,5-trimethyl-2-cyclohexenone (33)[b]	Infrared, ultraviolet,[e] anal., n.m.r.
	2,3,5-Trimethylphenol (*ca.* 10)[b]	Infrared, g.l.p.c.
	6-Chloro-2,3,5-trimethylphenol	g.l.p.c.[g]
	2-Chloro-3,4,5-trimethylphenol	g.l.p.c.[g]
Methyl vinyl ketone	3-Chloro-3-buten-2-one (50)[b]	Infrared, ultraviolet, g.l.p.c.
Mesityl oxide	*cis*-4-Chloromethyl-3-penten-2-one (8)[b,h]	Ultraviolet, infrared, g.l.p.c., n.m.r.
[Isomesityl oxide]	[1][b,h]	
	trans-4-Chloromethyl-3-penten-2-one (18)[b,h]	Anal., ultraviolet, infrared, n.m.r.
	[12][a,h]	
	1-Chloro-4-methyl-4-penten-2-one (17)[b,h]	Infrared, ultraviolet
	[26][b,h]	
	3-Chloro-4-methyl-4-penten-2-one (17)[b,h]	Infrared, ultraviolet
	[31][b,h]	
	1-Chloro-4-methyl-3-penten-2-one (3)[b,h]	. . .
	[6][b,h]	
	Unknown D (37)[b,h] [24][b,h]	

[a] In dimethylformamide containing lithium chloride. [b] By gas phase chromatographic analysis. [c] Infrared spectrum. [d] Characteristic retention time in g.l.p.c. [e] Ultraviolet spectrum. [f] Nuclear magnetic resonance spectrum. [g] Comparison with retention times observed in g.l.p.c. analysis of chlorination product of appropriate phenols. [h] Proportion of chlorinated product. [i] Probable structure.

that **B′** had a chlorine substituent on the 3-carbon, an assignment supported by the ratio (1.5) of infrared absorption intensities (**A**/**B′**) in the 1440-cm.$^{-1}$ region (asymmetric methyl and methylene deformations).

The peak labeled **C′** is thought to represent the 1-chloro-4-methyl-3-pentenone. It could not be isolated in sufficient quantity for detailed examination. The corresponding bromo ketone prepared by Cole[9] was thus probably a mixture of conjugated and unconjugated isomers.

A high boiling material (**D**) was isolated from the reaction products of both mesityl oxide and isomesityl oxide. It was not identified.

Mechanism.—The results of the copper(II) chloride chlorination of unsaturated ketones are summarized in Table 1.

Two salient features of the copper(II) halide halogenation are that (a) the relative rates[3] of reaction of ketones imply that enolization is an intermediate step and (b) the nature and distribution of the halogenation products imply a complex transition state.

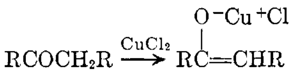
Shechter, Dessy,[10] and co-workers have demonstrated that cyclobutanone, cyclopentanone, and cyclohexanone have relative rates of 1, 150, and 793, respectively, in acid-catalyzed bromination. The relative rates of copper(II) bromide disappearance in the presence of excess ketone are 1, 32, and 85, respectively.

The ready halogenation of phenols[3] also suggests enols as the usual intermediate in the copper(II) halide halogenation.

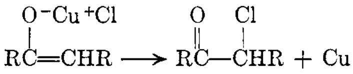
The preponderance of *para* chlorination and bromination in the reaction of phenol implies a mechanism appreciably different from other such halogenations,[11] as does the formation of the 3-chloromethyl-5,5-dimethyl-2-cyclohexenone from isophorone from which a distillable 4-bromo compound has been isolated in good yield by bromination with *N*-bromosuccinimide.[12]

There are at least three simple possibilities for a general mechanism of copper(II) halide halogenation. The first, a chain reaction involving intermediate free radicals, can be excluded on the basis of Kochi's finding that *p*-benzoquinone did not affect the reaction[13] and that the observed substitution patterns do not fit the expectations for free radical substitution.

A second pathway could involve two-electron reduction of copper(II) within a copper(II) enolate chloride complex (equations 11, 12, and 13). Kochi[13] has proposed essentially this mechanism. However, it would



$$\mathrm{RCOCH_2R} \xrightarrow{\mathrm{CuCl_2}} \mathrm{R\overset{\overset{\displaystyle O^-Cu^+Cl}{|}}{C}{=}CHR} \qquad (11)$$

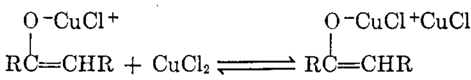


$$\mathrm{R\overset{\overset{\displaystyle O^-Cu^+Cl}{|}}{C}{=}CHR} \longrightarrow \mathrm{R\overset{\overset{\displaystyle O}{\|}}{C}{-}\overset{\overset{\displaystyle Cl}{|}}{C}HR} + \mathrm{Cu^\circ} \qquad (12)$$

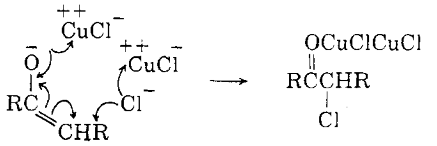
$$\mathrm{Cu^\circ} + \mathrm{Cu(II)} \longrightarrow \mathrm{2Cu(I)} \qquad (13)$$

seem difficult to account for the observed substitution pattern in phenol in terms of equation 12.

A third mechanism seems to us more satisfactory in accounting for our results. Two-electron reduction can be achieved through *simultaneous* one-electron reduction of two copper(II) species (equations 14 and 15).



$$\mathrm{R\overset{\overset{\displaystyle O^-CuCl^+}{|}}{C}{=}CHR} + \mathrm{CuCl_2} \rightleftharpoons \mathrm{R\overset{\overset{\displaystyle O^-CuCl^+CuCl_2}{|}}{C}{=}CHR} \qquad (14)$$



(15)

The connection between the copper(II) ions is achieved by means of a halide bridge.[14]

---

[10] H. Shechter, M. J. Collis, R. Dessy, Y. Okuzumi, and A. Chen, *J. Am. Chem. Soc.*, **84**, 2905 (1962).

[11] D. R. Harvey and R. O. C. Norman, *J. Chem. Soc.*, 3604 (1961).

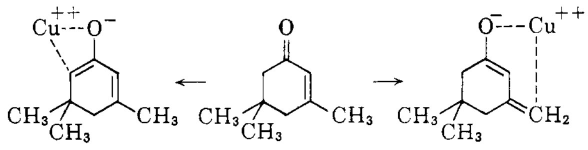
[12] A. J. B. Edger, S. H. Harper, and M. A. Kazi, *ibid.*, 1083 (1957).

[13] J. K. Kochi, *J. Am. Chem. Soc.*, **77**, 5274 (1955).

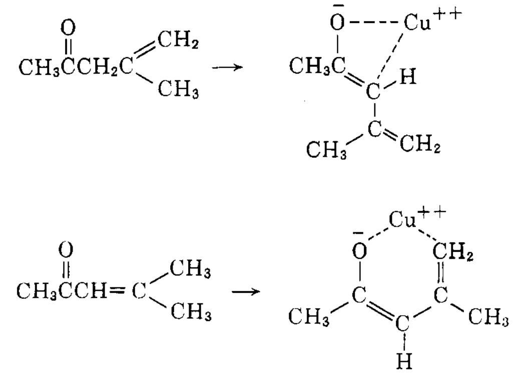
[14] *Cf.* discussion in Sec. 2.11, E. M. Kosower, "Molecular Biochemistry," McGraw Hill Book Co., New York, N. Y., 1962.

The formation of cyanogen from copper(II) and cyanide is second order in copper(II) and sixth order in cyanide.[15] Complexation of the copper(II) with ethylenediamine tetraacetic acid (EDTA) still leads to a reaction with cyanide which is second order in copper(II).[16] The facility with which many diynes form cyclic diacetylenes[17-19] as well as the excellent yields obtained in the oxidative dimerization of acetylenes with copper(I)[20] implies a compulsive simultaneity in the formation of the moieties which form the diacetylene linkage. These observations, as well as those involving oxidative coupling of phenols,[21] seem readily explicable in terms of simultaneous one-electron reduction of two copper(II) species. Moreover, the formation of cystine from cysteine and iron(III) has been ascribed to such a process.[22a] It should also be mentioned that the half-order dependence on copper(II) noted by Kochi[13] can be ascribed to the preponderance of a dimeric form of copper(II) and a rate-determining enolization. Rate-determining enolization in oxidation of α hydroxy ketones by copper(II) in alkaline solution has been shown.[22b]

The two chloro ketones derived from isophorone imply two different copper enolate intermediates (equation 16). The fact that mesityl oxide and isomesityl oxide do not give the same ratio of substitution products on the butenyl side of the carbonyl group is in accord with the intermediacy of two different copper enolates which are interconverted less rapidly than they are transformed into chloro ketones (equation 17). Coördination complexes of copper(II) are known which exist in two coördination arrangements depending on medium.[22c]



(16)



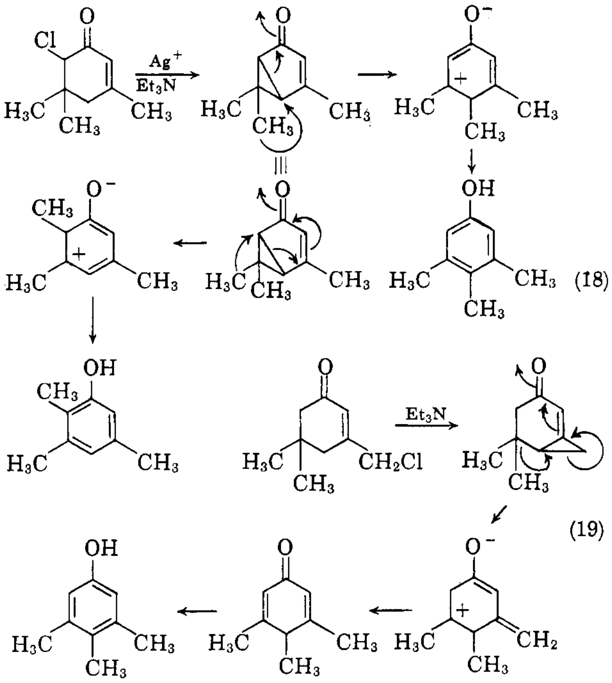
(17)

One other set of experiments deserves comment. Fort[23] has isolated 3,4,5-trimethylanisole from the reaction of copper(II) bromide and isophorone in methanol. He has also found that 6-tosyloxy-3,5,5-trimethyl-2-cyclohexenone forms 3,4,5-trimethylphenol in the presence of hydrogen chloride in dioxane,[24a] mentioning that the starting material was recovered almost quantitatively if treated with a "trace" of 2,6-lutidine in methanol for one week at 65°; however, with sodium methoxide and methanol, a combination of replacement and Favorskiĭ rearrangement products are found.[24b]

We have found that 6-chloro-3,5,5-trimethyl-2-cyclohexenone reacts very slowly with silver nitrate and triethylamine in acetonitrile to give after 50 hours at 80° a 40% yield of a mixture of 2,3,5-trimethylphenol (three parts) and 3,4,5-trimethyl phenol (two parts).

The isomeric ketone, 3-chloromethyl-5,5-dimethylcyclohexenone, yields 50% 3,4,5-trimethylphenol after 38 hours reflux in triethylamine.

These transformations can be rationalized as shown in equations 18 and 19.



(18)

(19)

Experimental

Cyclohexenone.—Chlorination of cyclohexenone[25] for 4 hr. at 90° followed by the usual isolation with ether gave 65% phenol, $n^{23.5}\mathrm{D}$ 1.5280, dark violet color with ferric chloride, b.p. 90–95°/20 mm., infrared spectrum identical to that of an authentic sample. The *N*-α-naphthyl carbonate derivative had m.p. 132–133°. Shorter reaction time (1.5 hr.) gave the same result.

3-Methylcyclohexenone.—The ketone, b.p. 93–95°/24 mm., $n^{23}\mathrm{D}$ 1.4921, was chlorinated at 90–93° for 20 min. After extraction with ether, 66% of *m*-cresol was found through g.l.p.c. analysis. A sample isolated by g.l.p.c. had the same infrared spectrum as authentic *m*-cresol. A second experiment, in which the reaction time was reduced to 10 min., led to 48% *m*-cresol. No other products, *e.g.* chloro ketones, were detected.

Isophorone.—Yellow technical grade 3,5,5-trimethyl-2-cyclohexenone-1 (isophorone, Eastman Yellow Label) was fractionated twice to give faintly yellow liquid, b.p. 88–89°/19–20 mm., $n^{24}\mathrm{D}$ 1.4756.

Pure isophorone (25.8 g., 0.187 mole) was added rapidly to a solution of copper(II) chloride hydrate (58.7 g., 0.344 mole) and lithium chloride (14.6 g., 0.344 mole) in dimethylformamide (250 ml.) held at 90–95°. As soon as the color changed from dark

---

[15] J. H. Baxendale and D. T. Westcott, *J. Chem. Soc.*, 2347 (1959).

[16] N. Tanaka, M. Kamada, and T. Marayana, *Bull. Chem. Soc. Japan*, **31**, 895 (1958).

[17] F. Sondheimer, Y. Amiel, and R. Wolovsky, *J. Am. Chem. Soc.*, **81**, 4600 (1959).

[18] M. Nagakawa and F. Toda, *Chem. Ind.* (London), 458 (1959).

[19] D. M. Behr, G. Eglinton, and R. A. Raphael, *ibid.*, 699 (1959).

[20] C. Glaser, *Ber.*, **2**, 422 (1869).

[21] A. S. Hay, H. S. Blanchard, G. F. Endres, and J. W. Eustance, *J. Am. Chem. Soc.*, **81**, 6335 (1959).

[22] (a) D. L. Leussing and L. Newman, *ibid.*, **78**, 5526 (1956); (b) B. A. Marshall and W. A. Waters, *J. Chem. Soc.*, 1579 (1961); (c) T. N. Waters and D. Hall, *ibid.*, 1200 (1959).

[23] A. W. Fort, *J. Org. Chem.*, **26**, 765 (1961).

[24] (a) A. W. Fort, *ibid.*, **26**, 332 (1961); (b) A. W. Fort, *J. Am. Chem. Soc.*, **84**, 2625 (1962).

[25] We are grateful to Dr. K. Williamson for this material.

brown to orange (*ca.* 20 min.), ice (250 g.) was added to stop the reaction. Ice was added until a precipitate of copper(I) chloride appeared. The latter was redissolved with a little dimethylformamide and the whole extracted five times with pentane. (*The product was lachrymatory; all manipulations were conducted in a hood. It is desirable that rubber gloves be worn during operations in which contact with the skin can occur.*) The combined pentane extracts were washed several times with water, dried over sodium sulfate and the solvent removed under reduced pressure. The yellow residue weighed 23.0 g. and contained no nitrogen by a sodium fusion test. Hydrolysis in 1% ethanolic sodium hydroxide and titration with silver nitrate, using an automatic titrator with carbon and platinum electrodes, indicated a 70–75% monochloro ketone content.

Crude chloro ketone (20 g.) was fractionated through a Teflon spinning band column[26] to yield isophorone (5.2 g.), b.p. 32–41°/0.2–0.4 mm., and three fractions containing substantial amounts of chloro ketone, (1) b.p. 41°/0.5 mm., 1.1 g., $n^{23}\mathrm{D}$ 1.5029; (2) b.p. 66–68°/0.7 mm., 2.1 g., $n^{22}\mathrm{D}$ 1.5189 (88% chloro ketone), and (3) b.p. 78–86°/0.9–1.4 mm., 4.0 g., $n^{22}\mathrm{D}$ 1.5189 (80% chloro ketone). Two careful chromatographies on Florisil with pentane, ether, and chloroform of fraction 4 gave small amounts of two chloroketones along with some phenols. The course of the chromatography was followed by g.l.p.c. on an 8-ft. column of 7.5% polyethylene glycol 600 distearate operated at 245–247° and conditioned for 40–48 hr. before use. *The column properties were critical;* one packing was suitable for 50 to 70 samples before decreased separation efficiency required a new column.

One chloro ketone, 3-chloromethyl-5,5-dimethyl-2-cyclohexenone (A), was faintly yellow and not very lachrymatory, $n^{24}\mathrm{D}$ 1.5023.

Anal. Calcd. for $\mathrm{C_9H_{13}OCl}$: C, 62.61; H, 7.59; Cl, 20.54. Found: C, 62.44; H, 7.66; Cl, 20.42.

$\bar{\nu}_{\mathrm{C=O}}$ 1658 cm.$^{-1}$ (liquid film) [$\bar{\nu}_{\mathrm{C=O}}$ (isophorone) 1660 cm.$^{-1}$]. $\lambda_{\max}$ (isoöctane) 2250 Å. (ϵ 14,300), 3363 Å. (ϵ 34) [$\lambda_{\max}$ (isophorone–isoöctane) 2253 Å. (14,200), 3367 Å. (ϵ 31)]. N.m.r. spectrum (12% in $\mathrm{DCCl_3}$) (benzene = 0) 320 (*gem*-dimethyl), 245 (methylene), 133 (methylene of chloromethyl), and 12 c.p.s. (alkene hydrogen) with approximate relative areas (by weight) of 7:4:2:1.

The other chloro ketone, 3,5,5-trimethyl-6-chloro-2-cyclohexenone (B) was an almost colorless, very lachrymatory oil, $n^{24}\mathrm{D}$ 1.5047.

Anal. Calcd. for $\mathrm{C_9H_{13}OCl}$: C, 62.61; H, 7.59; Cl, 20.54. Found: C, 62.59, 62.74; H, 7.66, 7.62; Cl, 20.46, 20.39.

$\bar{\nu}_{\mathrm{C=O}}$ 1675 cm.$^{-1}$. $\lambda_{\max}$ (isoöctane) 2429 Å. (ϵ 10,000), 3218 (ϵ 32). N.m.r. spectrum (sample contaminated with *ca.* 15% chloro ketone A, according to g.l.p.c.) (15% in $\mathrm{DCCl_3}$) 320 (*gem*-dimethyl), 258 (3-methyl), 240 (methylene), 141 (—CHClCO—), and 35 c.p.s. (alkene hydrogen) with the *approximate* areas 6:3:2:0.6:0.6 (corrected for A). The isolation of B in quantity was quite difficult.

Three phenols were obtained. One, 6-chloro-2,3,5-trimethylphenol (C), crystallized from the distillate of crude chloro ketones. The others were obtained as indicated above from chromatography on Florisil.

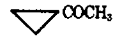
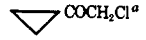
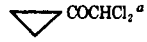
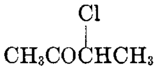
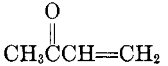
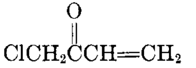
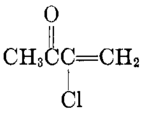
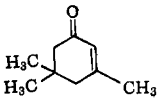
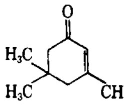
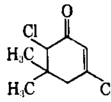
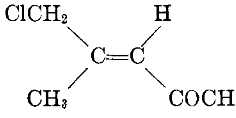
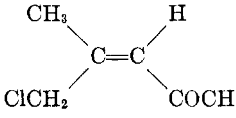
The phenol C had m.p. 89.1–90.5° after four recrystallizations from petroleum ether and gave an intense violet color with ferric chloride. The identification of C rests upon the retention time observed for the first g.l.p.c. peak for the product of chlorination of 2,3,5-trimethylphenol by copper(II) chloride and lithium chloride in dimethylformamide. The g.l.p.c. pattern for chlorophenols has been established,[3] permitting assignment of structure even though the major product isolated from the chlorination reaction appeared to be 4-chloro-2,3,5-trimethylphenol, m.p. 111.5–113.0° (recrystallized from petroleum ether) (reported,[27] m.p. 103–104°).

Phenol D was identical in all respects (m.p. 93.7–94.7°, light green flash with ferric chloride, g.l.p.c. retention time, infrared spectrum) with authentic 2,3,5-trimethylphenol.

Phenol E had a melting range of 66.5–73.0° even after five recrystallizations from petroleum ether. G.l.p.c. showed that only a single component was present and that this had a retention time identical to the first peak in the g.l.p.c. pattern for the product of copper(II) chloride chlorination of 3,4,5-trimethylphenol. Phenol E was therefore 2-chloro-3,4,5-trimethylphenol.

Table II

Ultraviolet Spectroscopic Data for ChloroKetones

		Transitions	
Compound	Solvent	n → π* $\lambda_m(\epsilon_m)$	π → π* $\lambda_m(\epsilon_m)$
	IO[b]	2772 (15)	1878 (5,600)
	IO	2854 (37)	1955 (5,100)
	IO	2890 (59)	2010 (3,600)
 $\mathrm{CH_3CO\overset{Cl}{C}HCH_3}$	*i*-PrOH	2920 (41)	
 $\mathrm{CH_3\overset{O}{\overset{\Vert}{C}}CH{=}CH_2}$	IO	3304 (20)	2040 (8,500)
 $\mathrm{ClCH_2\overset{O}{\overset{\Vert}{C}}CH{=}CH_2}$	IO	3361 (38)	2140 (7,800)
	$\mathrm{CH_3CN}$	3221 (29)	2119 (8,500)
	$\mathrm{CH_3OH}$	3220 (30)	2128 (7,800)
	TFP[c]	3106 (32)	2133 (9,800)
 $\mathrm{CH_3\overset{O}{\overset{\Vert}{C}}\underset{Cl}{C}{=}CH_2}$	IO	3160 (–)[e]	2295 (9,000)
	IO	3367 (32)	2253 (14,000)
	IO	3363 (34)	2250 (14,000)
	IO	3218 (32)	2429 (10,000)[d]
	$\mathrm{CH_3CN}$		2471 (10,200)[d]
	$\mathrm{CH_3OH}$		2495 (10,000)[d]
	TFP		2540 (9,500)[d]
$\mathrm{(CH_3)_2C{=}CHCOCH_3}$	IO	3284 (39)	2304 (11,900)
	IO	3337 (70)	2400 (11,900)
	IO	3314 (81)	2446 (10,300)

[a] See ref. 3. [b] Isoöctane. [c] 2,2,3,3-tetrafluoropropanol. [d] Linear in **Z** [E. M. Kosower, J. *Am. Chem. Soc.*, **80,** 3253(1958)]. [e] Low solubility and limited material precluded accurate measurement of ϵ.

The assignment of structures to almost every peak allowed an analysis of the crude product of the chlorination reaction. A typical composition was isophorone (25%) chloro ketone A (35%), chloro ketone (33%), and phenols (7%). A minor unidentified peak was due to a saturated ketone formed by rearrangement of chloro ketone A on the column in the presence of hydrogen chloride.

Chloro ketone A (containing 5% chloro ketone B) (92 mg.) was refluxed in 6 ml. of triethylamine for 38 hr. Triethylamine hydrochloride (34 mg.) was filtered off and the solvent removed to leave *ca.* 60 mg. of oil. G.l.p.c. analysis indicated a 50% yield of 3,4,5-trimethylphenol, confirmed by the similarity of an infrared spectrum of material eluted from a Florisil column, to an authentic sample of the phenol.

Chloro ketone B (*ca.* 95% pure) (218 mg.) was refluxed in 12 ml. of triethylamine for 52 hr. Removal of solvent and g.l.p.c. analysis showed that little reaction had taken place. Silver nitrate (220 mg.) in 2 ml. of acetonitrile and 3 ml. of triethylamine were added to the residual oil and the whole heated 50 hr. Chromatography on Florisil gave a 40% yield of a mixture of 2,3,5-trimethylphenol and 3,4,5-trimethylphenol in the ratio 3:2, identified by g.l.p.c. peak position and the identity of the infrared spectrum to a known mixture of the two phenols.

---

[26] The Teflon band and column were supplied by Nester and Faust, Inc., Wilmington, Del.

[27] J. S. Fitzgerald, *J. Appl. Chem.* (London), **5,** 289 (1955).

Methyl Vinyl Ketone.—Methyl vinyl ketone (K & K Laboratories) (redistilled, b.p. 79°, $n^{24}D$ 1.4089, pure by g.l.p.c.) (10.0 g.) was stirred vigorously with copper(II) chloride hydrate (48.8 g.) and lithium chloride (6.1 g.) in dimethylformamide for 40 min. at 75–85°. Continuous extraction by pentane (91 hr., followed by optical density at 3300 Å.) yielded 3 g. of oil. Multifold extraction with pentane of a similar reaction mixture gave 2.2 g. of oil. The latter material (15% chloro ketone by g.l.p.c.) was fractionated through a Teflon spinning band column to yield 0.4 g. of distillate in three fractions (the pot contained a viscous black liquid). Pure chloro ketone, b.p. 50–60°/75 mm., was isolated from the third fraction (100 mg.) by g.l.p.c. on 7.5% polyethylene glycol 600 distearate at 135°. The ketone became a black viscous mass on standing in the refrigerator for 1 month. $\tilde{\nu}_{C=O}$ 1705 cm.$^{-1}$., λ_{max} (isoöctane) 3160 Å., 2295 Å. (ϵ 9000). The corresponding figures for methyl vinyl ketone are $\tilde{\nu}_{C=O}$ 1680 cm.$^{-1}$, λ_{max} (isoöctane) 3304 Å. (ϵ 20), 2040 Å. (ϵ 8500). The properties of the chloro ketone were identical to those of 3-chloro-3-butenone which was synthesized in 4% yield by the method of Petrov and Leporskaya[6] and quite different from those of 1-chloro-3-buten-2-one prepared by the reaction of ethylene, aluminum chloride, and chloroacetyl chloride.[7] Although the yield of 3-chloro-3-butenone isolated as above was quite low, g.l.p.c. analysis of the crude product indicated that 30–40% of chloro ketone was present.

Mesityl Oxide.—Redistilled ketone (3.5% isomer by g.l.p.c.) was chlorinated at 90–95°. The color lightened appreciably after 15 min., then became dark black. After 20 min. reaction, oil was isolated in the usual way with pentane (14 g. from 24 g. of starting ketone.) G.l.p.c. analysis of the crude product is illustrated in Fig. 1, using 20% polyethylene glycol 600 distearate on firebrick. Fractional distillation of the oil under reduced pressure gave mixtures which could be resolved into reasonably pure components by g.l.p.c.

Isomesityl oxide (69% pure by g.l.p.c.)[28] was chlorinated to give a yellow oil. Comparison of the g.l.p.c. analysis of the oil with that of the mesityl oxide product revealed that components **A**, **B′**, and **C′** increased and components **B**, **C**, and **D** decreased in yield.

From a fraction containing **B** and **C** (b.p. 80–92°/30 mm.), chloro ketones **B** and **C** were separated by g.l.p.c., 20 λ at a time, to give small quantities of the pure ketones.

Ketone B: *Anal.* Calcd. for C_6H_9OCl: C, 54.35; H, 6.84; Cl, 26.74. Found: C, 54.15; H, 6.78; Cl, 26.35, 26.49.

N.m.r. spectrum (capillary benzene reference = 0, internal hexamethyldisiloxane (HMD) = 384 c.p.s.) (in c.p.s.) 271, 255, 145, and 12.3 with area ratios *ca.* 3:3:2:1. $\tilde{\nu}_{C=O}$ (liquid film) 1678 cm.$^{-1}$; $\lambda_{max}^{isooctane}$ 2400 Å. (ϵ 11,900), 3337 Å. (ϵ 70).

Ketone C showed carbonyl absorption at 1686 cm.$^{-1}$; 245 mμ (ϵ 10,300), 331 mμ (ϵ 81) in isoöctane. The n.m.r. spectrum is very similar to that of **B** except for a low intensity peak at 38 c.p.s. The chloro ketone **C** is very unstable and satisfactory combustion data could not be obtained. G.l.p.c. analysis of a sample trapped from g.l.p.c. indicated the presence of both hydrogen chloride and a volatile compound, some of which are lost before combustion. Both **B** and **C**, when freshly prepared, were colorless and lachrymatory.

The products **A** and **B′** were trapped directly from the crude product by g.l.p.c. since they disappear during attempted fractional distillation. The presence of high boiling material in the product and the lack of a preparative g.l.p.c. apparatus permitted only the collection of sufficient material for infrared and ultraviolet absorption measurements. Both compounds gave positive tests for chlorine after destruction by fused sodium. **Ketone A:** $\tilde{\nu}_{C=O}$ 1709 cm.$^{-1}$ (in $CHCl_3$), $\lambda_{max}^{isooctane}$ 2809 A. (ϵ 390). **Ketone B′:** $\tilde{\nu}_{C=O}$ 1718 cm.$^{-1}$ (in $CHCl_3$), $\lambda_{max}^{isooctane}$ 2810 (ϵ 340). It must be noted that the retention times of these two ketones in g.l.p.c. were quite different.

Product **C′** was present in such small quantities that it could not be isolated.

Product **D** could be isolated as a faintly yellow liquid, b.p. 67°/0.6 mm. and represented almost 40% of the product of chlorination of mesityl oxide (23% of the isomesityl oxide chlorination product). $\tilde{\nu}_{max}$ 2950 (s), 1695 (w), 1618 (w), 1355 (m) cm.$^{-1}$; $\lambda_{max}^{isooctane}$ 2208 Å. (ϵ 8400), 2847 Å. (ϵ 180).

Anal. Found: C, 71.03; H, 8.72; Cl, 4.54.

The analysis of a sample after treatment with silver nitrate was almost identical. N.m.r. spectrum (capillary benzene = 0 c.p.s., HMD = 384 c.p.s.) (in c.p.s.) 294, 265, 254, 244, 213, 45.3 with approximate relative areas of 3.5:2:2:2:1. The product was not further investigated but is probably formed from two moles of monochloro ketone followed by loss of hydrogen chloride.

Ultraviolet Spectra.—Spectra were carefully measured with either a Cary Model 11 or Model 14 recording spectrophotometer. The spectroscopic results are summarized in Table II.

---

(28) F. H. Stross, J. M. Monger, and H. de V. Finch, *J. Am. Chem. Soc.*, **69**, 1627 (1947).

Oxidation by Solids. II. The Preparation of Either Tetraarylethanes or Diaryl Ketones by the Oxidation of Diarylmethanes with Manganese Dioxide

ERNEST F. PRATT AND STUART P. SUSKIND[1,2]

Department of Chemistry, University of Maryland, College Park, Maryland

Received September 24, 1962

It has been found that, when a solution of a diarylmethane in biphenyl and benzene is heated under reflux (211°) with manganese dioxide in an apparatus equipped with a water trap, good yields of the corresponding tetraarylethanes as well as the by-product water usually are obtained. The effects of changes in structure of the diarylmethanes on the rate of the reaction are consistent with the proposal that the reaction proceeds *via* free radical intermediates. When the same diarylmethanes and manganese dioxide, in 1:10 weight ratio, are heated at 125° in the absence of a solvent good yields of the corresponding diaryl ketones are usually obtained.

A procedure for oxidizing a variety of diarylmethanes to the corresponding tetraarylethanes in good yield has been developed. The diarylmethane and manganese dioxide in biphenyl and benzene are heated under reflux (211°) in an apparatus equipped with a Dean–Stark trap. Approximately the theoretical yield of water ordinarily collects in the trap and since smooth curves of the same general shape are obtained upon plotting the volume of water collected against time, the times required for a 50% yield of water to collect ($t_{50\%}$) are valid measures of the relative rates of reaction. The $t_{50\%}$ values were found to be closely reproducible.

$$2ArCH_2Ar' + MnO_2 \longrightarrow ArAr'CHCHAr'Ar + MnO + H_2O \tag{1}$$

In Table I results for six symmetrical and seven unsymmetrical diarylmethanes are listed in order of decreasing reaction rate. For both the symmetrical and unsymmetrical reactants the *para*-phenyl substituents increased the rate over that for the unsub-

---

(1) From the Ph.D. thesis of S. P. Suskind, April, 1962.

(2) For the previous paper in this series, see E. F. Pratt and John F. Van de Castle, *J. Org. Chem.*, **26**, 2973 (1961).