TABLE II

ULTRAVIOLET ABSORPTION MAXIMA FOR SOME ALKYL-SUBSTITUTED ANTHRACENES[a]

Substituent(s) on anthracene	λ_{max}[b] mμ	Log ε	λ_{max} mμ	Log ε	λ_{max}[b] mμ	Log ε	λ_{max} mμ	Log ε	λ_{max} mμ	Log ε	λ_{max} mμ	Log ε	λ_{max} mμ	Log ε	λ_{max} mμ	Log ε
1-Ethyl	(251	5.15)	254	5.23	311	3.12	326	3.48	341	3.77	358	3.93			376	3.89
2-Ethyl	246	5.00	254	5.37	(310	3.10)	323	3.41	339	3.65	356	3.80			374	3.75
2-*t*-Butyl	246	5.03	254	5.39	(308	3.11)	322	3.42	337	3.67	354	3.82			372	3.77
9-Ethyl	248	4.98	256	5.33	316	3.07	331	3.48	347	3.81	364	4.03	378	3.74	383	4.03
9-*n*-Propyl	248	4.98	256	5.32	316	3.06	331	3.47	347	3.82	364	4.03	378	3.74	383	4.03
9-*n*-Decyl	248	4.93	256	5.27	316	3.07	331	3.45	347	3.79	365	4.01	379	3.72	383	4.01
2,6-Dimethyl	248	5.00	256	5.38			333	3.54	350	3.61	358	3.65			378	3.66
2,7-Dimethyl	248	4.98	256	5.35			329	3.42	340	3.62	356	3.74			374	3.62
2,6,9-Trimethyl	251	4.98	260	5.41			338	3.51	352	3.68	368	3.72			386	3.76

[a] Solvent, isoöctane. [b] Data in parentheses are for shoulders, not true maxima.

trimethylanthracene, m.p. 77–78°. The latter compound was recrystallized thrice from ethanol to give pale yellow, strongly fluorescent (purple) leaflets, m.p. 86.5–87.5°.

Anal. Calcd. for $C_{17}H_{16}$: C, 92.68; H, 7.32. Found: C, 92.43; H, 7.55.

Tetra- and Hexamethylanthracenes.—Samples of these compounds[43] were kindly supplied by Dr. Enno Wolthuis for use in these studies.

Polarography.—Only analytically pure hydrocarbons were used in polarographic studies. Such samples were prepared by first recrystallization of the available compounds to narrow melting range (1–2°), then (in many cases) chromatography, and finally at least two recrystallizations from an appropriate solvent within 2 weeks of running the polarogram. Melting ranges on the compounds used were no greater than 1°. The polarographic apparatus and procedure were the same as previously described.[7] Each compound was run at three different concentrations (*ca.* 3.5, 6.3, and 8.3 × 10^{-4} *M*) in succession. Several compounds were run from time to time over a period of more than one year and with occasional repurification. For each compound the various values of $E_{1/2}$ found were within ± 3 mv. of the average value. All polarograms were regular in shape. Calculations were made by taking the instantaneous current as the maxima of the pen oscillations. The diffusion current i_d was determined for the most dilute solution of the hydrocarbon and was calculated as $^6/_7$ of the vertical distance between the residual current (a straight line extended) and the limiting current (represented by a line parallel to the one for the residual current). Polarographic data are given in Table I.

Ultraviolet Spectra.—Ultraviolet absorption spectra of those hydrocarbons for which such data were not readily available were determined in spectral grade isoöctane using a Cary Model 11 spectrophotometer. Data on the absorption maxima are presented in Table II.

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(43) E. Wolthuis, *J. Org. Chem.*, **26**, 2215 (1961).

Halogenation with Copper(II). I. Saturated Ketones and Phenol

EDWARD M. KOSOWER,[1] W. J. COLE,[2a] G.-S. WU,[2b] D. E. CARDY, AND G. MEISTERS[2c]

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

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A procedure for halogenation of enolizable compounds using copper(II) chloride or bromide in dimethylformamide is described. Methyl ethyl ketone yields 55–70% 3-chlorobutanone, methyl cyclopropyl ketone yields both chloromethyl and dichloromethyl cyclopropyl ketones, propiophenone gives an excellent yield of α-chloropropiophenone, and phenol leads to *o*- and *p*-chlorophenols, in a ratio (1:6) substantially different from that of other chlorination methods, along with some 2,4-dichlorophenol. A convenient test for relative reactivities of enols and enolizable compounds is also included.

Copper(II) reactions are of great interest because of such organic reactions as the oxidative dimerization of acetylenes and such biochemical reactions as the oxidation of tyrosine by the copper-containing enzyme, tyrosinase. Copper(II) halogenation was selected as a possible model for these oxidations. An examination of the reaction with a variety of substrates is reported in this paper and the succeeding one.[3–5]

In 1897, Ley[6] reported that the conductivity of copper(II) chloride solutions in acetone increased with time. Kohlschütter[7] noted the formation of copper(I) chloride from these solutions, interpreted this as resulting from the disappearance of chlorine derived from reversible dissociation of copper(II) chloride into copper(I) chloride and chlorine, and suggested that the solution might be useful as a chlorinating agent. Others[8,9] have come across the same phenomenon. Although the formation of chloroacetone was an important facet of the Meerwein reaction of aryldiazonium ions with alkenes, it was ignored as a side reaction.[10] In one case, for example, a 65% yield of chloroacetone was obtained from the reaction of 2,4-dichlorobenzene diazonium

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(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 (a) M.S. thesis of W. J. Cole, June, 1959; (b) Ph.D. thesis of G.-S. Wu, January, 1962; (c) B.S. thesis of G. Meisters, June, 1958.

(3) E. M. Kosower and G.-S. Wu, *J. Org. Chem.*, **28**, 633 (1963).

(4) Grateful acknowledgment is made for support from the Air Force Office of Scientific Research through contract AF 49 (638)-282 and to the National Institutes of Health under grant E-1608.

(5) (a) Presented in part at the 138th National Meeting of the American Chemical Society, New York, N. Y., September, 1960, Abstracts 138, 7-P; (b) The oxidation of phenols by copper–amine complexes and oxygen has been reported by W. Brackman and E. Havinga, *Rec. trav. chim.*, **74**, 937, 1021, 1070, 1100, 1107 (1955).

(6) H. Ley, *Z. physik. Chem.*, **22**, 83 (1897).

(7) V. Kohlschütter, *Ber.*, **37**, 1169 (1904).

(8) H. Jones and W. Veazey, *Z. physik. Chem.*, **61**, 641 (1908).

(9) P. Schulz "Verhalten von Salzen in Aceton," Dissertation, Giessen, 1901; cited by A. Nauman, *Ber.*, **37**, 4328 (1904).

(10) H. Meerwein, E. Buchner, and K. van Emster, *J. prakt. Chem.*, **260**, 248 (1939).

chloride in acetone with copper(II) chloride and sodium acetate.

Kochi[11] has carefully measured the stoichiometry of the reaction of copper(II) chloride with acetone in aqueous acetone mixtures and has found that it corresponds to equation 1. Kochi[11] also reported that diethyl ketone and acetophenone formed copper(I) chloride from copper(II) chloride in the presence of lithium chloride.

$$2CuCl_2 + CH_3COCH_3 \longrightarrow 2CuCl + ClCH_2COCH_3 + HCl \quad (1)$$

A number of recent publications have described reactions using copper(II) bromide, using either an alcohol[12,13] or dioxane[14] medium.

Two other reports concerning copper(II) halide reactions will be discussed in the following article.[3]

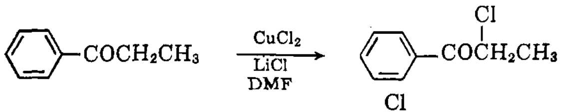
Results and Discussion

Dimethylformamide was chosen as a solvent for the halogenation with copper(II) halides for the following reasons: (a) solvent for both inorganic salts and organic compounds, (b) ability to neutralize the acid produced in the reaction [Kochi[11] had shown that the halogenation rate was reduced by acid], and (c) availability in quantity at reasonable cost. In addition, dimethylformamide was miscible with water, facilitating the isolation of organic products by extraction. Ethanol and acetonitrile proved to be unsatisfactory solvents in preliminary experiments. Hydroxylic solvents would not seem favorable choices for the preparation of reactive haloketones.

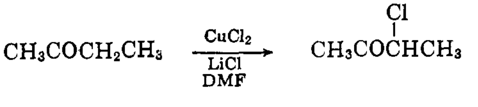
Propiophenone was converted to the α-chloro derivative in 89% yield, and a 72% yield of pure material could be isolated readily. The reaction of α-chloropropionyl chloride with benzene and aluminum chloride results in α-chloropropiophenone in 66% yield.[15] The procedure described in the Experimental is generally applicable to most of the compounds investigated in detail (equation 2).

Methyl ethyl ketone led to only one product, the 3-chlorobutanone, an unstable compound, in 55–70% yield (equation 3).

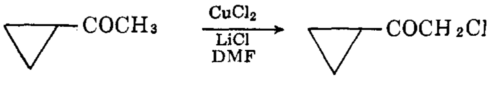
Methyl cyclopropyl ketone formed two products in roughly equal quantity. The analysis and spectroscopic data (infrared ultraviolet, n.m.r.) confirmed the structure of the most readily isolated product as chloromethyl cyclopropyl ketone. The second ketone was probably dichloromethyl cyclopropyl ketone, although the chlorine analysis for the unstable compound was very much lower than expected. The infrared, ultraviolet, and n.m.r. spectra, however, support the proposed structure. Its formation is no doubt due to the greater reactivity of the monochloromethyl cyclopropyl ketone in comparison with methyl cyclopropyl ketone (equations 4 and 5). Dicyclopropyl ketone failed to react (to any extent detectable by gas chromatography) under conditions much more vigorous than those usually used.



(2)



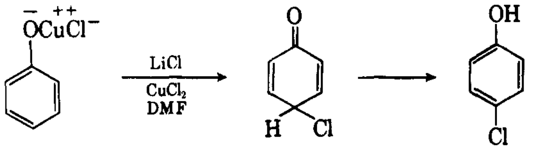
$$CH_3COCH_2CH_3 \xrightarrow[\text{LiCl, DMF}]{CuCl_2} CH_3CO\overset{Cl}{C}HCH_3$$
(3)



(4)

(5)

Chlorination of phenol with chlorine gives a mixture of monochlorophenols which vary in composition from *para/ortho* 1.7:1 in molten phenol[16] to 1:2.8 in carbon tetrachloride.[17] Chlorination of phenol with sulfuryl chloride[18] is claimed to form *p*-chlorophenol exclusively. The reaction of phenol with copper(II) chloride forms a mixture of chlorophenols in which the *para/ortho* ratio varied from 6:1 to 10:1 in an irregular fashion, indicating a marked preference for *para* substitution (equation 6).



(6)

The addition of sufficient complexing agent (ethylene diamine) to occupy two of the four readily available coördination positions of the copper appeared to have no effect on the reaction of phenol other than reducing the degree of conversion to chlorophenols. Likewise, one-half mole of diethylenetriamine per mole of copper (II) had no effect. Greater quantities of these reagents or equivalent quantities of compounds with a greater number of coördinating groups inhibited chlorination altogether.

Bromination of phenol with copper(II) bromide led to a mixture of bromophenols with a *para/ortho* ratio of *ca.* 11:1.

Flitman and Frieden[19] have described a semiquantitative test for the reactivity of readily oxidizable compounds (*e.g.*, catechol, thiouracil, etc.) which utilizes the reduction of copper(II) to copper(I) and measures the formation of the latter with cuproin in a spectrophotometer.

A simpler and more generally useful test was devised on the basis of our observation that cupric bromide in dimethylformamide containing a small amount of lithium bromide changed from a deep (usually green) color to a pale yellow or colorless state upon reaction with excess phenol or ketone. The test is readily carried out upon 5 mg. of substance; it is best to simultaneously run a known phenol or cyclopentanone, so as to measure relative reactivities. In most cases, the reaction was carried out by immersing a test portion in boiling water until the color change was judged complete; some of the more reactive compounds were also examined at lower temperatures. Relative rate data are given for many compounds in the Experimental.

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

[12] P. B. Sollman and R. M. Dodson, *J. Org. Chem.*, **26**, 4180 (1962).

[13] E. R. Glazier, *ibid.*, **27**, 2937 (1962).

[14] K. B. Doifode, *ibid.*, **27**, 2665 (1962).

[15] R. Baker and G. Barkenbus, *J. Am. Chem. Soc.*, **58**, 263 (1936).

[16] G. H. Bing, W. W. Kennard, and D. N. Matthews, *Austral. J. Chem.*, **13**, 317 (1960).

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

[18] A. F. Holleman and I. J. Rinkes, *Rec. trav. chim.*, **30**, 89 (1911).

[19] R. Flitman and E. Frieden, *J. Am. Chem. Soc.*, **79**, 5198 (1957).

The mechanism of the copper(II) halide halogenation is discussed in the next article.[3]

Experimental

α-Chloropropiophenone.—A chlorination procedure suitable for many compounds is illustrated for the case of propiophenone.

In a 2-l., three-necked flask fitted with Teflon stirrer, thermometer, and reflux condenser were placed copper(II) chloride hydrate (425 g., 3.6 moles, 20% excess), lithium chloride (76.4 g., 1.8 moles), and dimethylformamide (900 ml.). After heating to 80°, propiophenone (fractionated, $n^{25}{}_{\mathrm{D}}$ 1.5247, 201.3 g., 1.5 moles) was added and the whole stirred at 80–90° for 1 hr. The dark reaction mixture was diluted with ice (900 g.) followed by sufficient dimethylformamide to redissolve a small amount of precipitated copper(I) chloride.

Rubber gloves and goggles are advised in subsequent steps since chloro and bromo ketones are vesicant or lachrymatory or both; operations should be conducted in a good hood. The solution was transferred to a 3-l. separatory funnel and extracted six times with 300-ml. portions of pentane. The combined extracts were washed with two 10-ml. portions of water, filtered through sodium sulfate, and the pentane removed by distillation. The residue (260 g.) was carefully fractionated through a 90-cm. glass helices-packed column at 18 mm., using high reflux ratios. A substantial forerun, b.p. 100–124°/16–18 mm., was analyzed as a mixture of propiophenone and α-chloropropiophenone by refractive index, with 12.6 g. of the former (6.3%) and 19.4 g. of the latter (7.7%). The next fraction, 25.4 g. (10.0%), appeared to be substantially pure α-chloropropiophenone (b.p. 121–126°/18 mm.) but was contaminated by a small amount of yellow impurity, probably phenyl methyl diketone in analogy to the diacetyl formed during the chlorination of methyl ethyl ketone. The major portion of the product was collected at 126.5–127°/18 mm.; yield, 188.1 g. (71.5%).

The physical properties (boiling point, refractive index, infrared and ultraviolet spectra of α-chloropropiophenone prepared in this manner were identical to those of an authentic sample prepared according to the literature.[15] However, the refractive index, $n^{25}{}_{\mathrm{D}}$ 1.5438, was higher than that reported ($n^{25}{}_{\mathrm{D}}$ 1.5402).[15] It was noted that rapid distillation of the material gave a liquid with the lower refractive index; $\lambda_{\max}^{\text{isooctane}}$ 2470 Å. (ϵ 12,800), 2825 Å. (ϵ 2100), 3272 Å. (ϵ 17).

3-Chlorobutanone.—Chlorination of methyl ethyl ketone at 80–90° for 45 min. led to only one isomer which was unstable, turning yellow and forming water on standing. Yields varied from 55–70% and appeared to be optimum for 1 mole of lithium chloride per mole of copper(II) chloride. Freshly refractionated 3-chlorobutanone had d_4^{20} 1.09, $n^{25}{}_{\mathrm{D}}$ 1.4220, b.p. 56°/100 mm., 112–113°/740 mm. Reaction with aniline gave 2,3-dimethylindole, m.p. 98–102° (reported[20] 107°) with a picrate, m.p. 156.5–158.5° (reported[20] 157°). The semicarbazone had a m.p. between 128 and 140°, depending on heating rate (reported[21] 138–139°).

Methyl Cyclopropyl Ketone.—The ketone (8.4 g.) (b.p. 110–111.5°, $n^{23.5}{}_{\mathrm{D}}$ 1.4229) was chlorinated at 90° for 3.5 hr. and worked up by extraction with pentane (six times) and ether (six times). After removal of the ether, the residue was extracted with pentane in the presence of a small amount of water (to interact with the dimethylformamide) and the very lachrymatory chloromethyl cyclopropyl ketone (2.5 g.) isolated by removal of the solvent. Redistillation afforded pure material, b.p. 77.0–77.5°/28 mm., $n^{26.5}{}_{\mathrm{D}}$ 1.4687.

Anal. Calcd. for C_5H_7OCl: C, 50.65; H, 5.95; Cl, 29.91. Found: C, 50.69; H, 5.92; Cl, 29.70

N.m.r. (15% in $DCCl_3$ at 60 Mc.) (benzene = 0, hexamethyldisiloxane = 384 c.p.s.) methyl cyclopropyl ketone 331,[22] 270,[22] 260 c.p.s. with relative areas 4:1:2.5. Chloromethyl cyclopropyl ketone 320,[22] 255[22] and 132 c.p.s. with relative areas 4:1:1.5. Infrared $\nu_{C=O}$ (doublet) 1704, 1715 cm.$^{-1}$. Ultraviolet $\lambda_{\max}^{\text{isooctane}}$ 2854 Å. (ϵ 37), 1955 Å. (ϵ 5100).

The pentane extracts yielded a mixture of chloromethyl cyclopropyl ketone and a second ketone which could not be separated from the first by fractionation through a spinning band column equipped with a Teflon spinning band.[23] Extraction of the mixture with dimethylformamide followed by separation through g.l.p.c. yielded a small sample of material assigned the structure dichloromethyl cyclopropyl ketone, $n^{26.5}{}_{\mathrm{D}}$ 1.4775.

Anal. Calcd. for $C_5H_6OCl_2$: C, 39.24; H, 3.95 Cl, 46.35. Found: C 39.90; H, 4.03; Cl, 32.70

N.m.r. ($DCCl_3$, 60 Mc.) 317,[22] 252,[22] and 31 c.p.s. with relative areas *ca.* 4:1:1. Infrared $\nu_{C=O}$ (doublet) 1724, 1691 cm.$^{-1}$. Ultraviolet $\lambda_{\max}^{\text{isooctane}}$ 2890 Å. (ϵ 59), 2010 Å. (ϵ 3600). The material darkened on a few hours exposure to air at room temperature. G.l.p.c. analysis (20% polyethylene glycol 600 distearate on firebrick at 150–155°) of the crude reaction product indicated 28% and 27% yields of mono- and dichloroketones. A shorter reaction period gave the same proportion of products at lower conversion.

Dicyclopropyl ketone failed to react with the usual chlorination mixture when heated at 115° for 2 hr.

Phenol.—Chlorination was carried out under various conditions in dimethylformamide. Products were extracted in a continuous extractor and analyzed by g.l.p.c., using either polyethylene glycol 400 monostearate (A) or distearate (B) (20%) on Johns-Manville acid-washed firebrick C-22 at 215°.[24] Retention times (in minutes) on Column A were dimethylformamide 5.7, *o*-chlorophenol 15.9, phenol 20.8, 2,6-dichlorophenol 35.8, 2,4-dichlorophenol 40.6, *p*-chlorophenol 66.3, and *m*-chlorophenol 73.1. The areas under the peaks were assumed proportional to the quantities of phenols present.

Conversions to chlorinated products (55–75% recovery of material) ranged from 40% (85°, 1 hour) to 80% (reflux, 5 min.). The products were *o*-chlorophenol, *p*-chlorophenol, and 2,4-dichlorophenol. The ratio of *o*- to *p*-chlorophenol ranged from 1:6 to 1:10, and the proportion of 2,4-dichlorophenol in chlorinated product from 5% (85°, 1 hr.) to 25% (reflux, 5 min.) Relative rates (*see below*) suggested that *o*-chlorophenol would be chlorinated faster than *p*-chlorophenol, indicating that the *o*:*p* ratios for initial reaction would be somewhat smaller than those given.

Addition [per mole of copper(II)] of one mole of ethylenediamine or one-half mole of diethylenetriamine to the reaction mixture (90°, 1 hr.) reduced conversions but did not change product proportions. One mole of diethylenetriamine, triethylenetetramine, or tetraethylenepentamine inhibited reaction completely, phenol being recovered in yields of 75, 56, and 26%, respectively.

Phenol could be brominated using copper(II) bromide to *o*-bromophenol (6%), *p*-bromophenol (67%), 2,4-dibromophenol (20%), 2,6-dibromophenol (6%), and 2,4,6-tribromophenol (4%) at 100° for 2 hr. Recovery 60%; conversion 75%.

Substituted Phenols.—Both *o*- and *p*-chlorophenol were chlorinated to 2,4-dichlorophenol in 42 and 37% yield, respectively, at 100° for 2 hr.

p-Bromophenol was brominated at 100° for 2 hr. to a mixture of 2,4-dibromophenol (17%) and 2,4,6-tribromophenol (27%) with 60% recovery.

p-Chlorophenol was brominated at 100° for 2 hr. to a mixture of 57% 2-bromo-4-chlorophenol and 37% 2,6-dibromo-4-chlorophenol with 30% recovery.

Relative Rates of Halogenation.—A qualitative test for the reactivity of various compounds was devised. The basis was the change in color of copper(II) bromide–dimethylformamide solutions from green to pale yellow or colorless on reaction with various substrates in excess. The reagent is a 0.01 *M* solution of copper(II) bromide and 0.001 *M* lithium bromide in dimethylformamide. The solution changed color noticeably over long periods of time and should be used within a month. The substrate was utilized as a solution of *ca.* 5 mg. in 50 μl. of dimethyl formamide. The disappearance of the color depends on a reasonable excess of substrate. A 50-μl. portion of copper(II) bromide solution was mixed with the substrate solution in a 2 in. centrifuge tube, using a *glass* rod to ensure mixing. The tube was placed in boiling water and the time required for the color disappearance was noted. It is useful to run a standard compound along with the unknown.

At 100°, the color change was observed in 105 ± 7 sec. for phenol. The blank was 8100 sec. With phenol as 1.00, the following relative rates were noted: [substituted phenols] 2-

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(20) A. Demetre-Vladesco, *Bull. Soc., Chim.*, [3] **6**, 404, 807 (1891).

(21) N. Rabjohn and G. Rogier, *J. Org. Chem.*, **11**, 781 (1946).

(22) Complex peaks characteristic of the cyclopropyl group are centered approximately at the position given.

(23) Obtained by special request from Nester & Faust, Inc., Wilmington, Del.

(24) Sixteen other columns were either ineffective or considerably less useful. The g.l.p.c. analysis of chlorophenols has been reported by J. A. Barry, R. C. Vasishth, and F. J. Shelton, *Anal. Chem.*, **34**, 67 (1962).

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

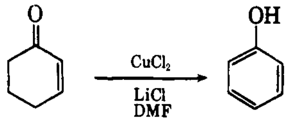
Received September 17, 1962

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]

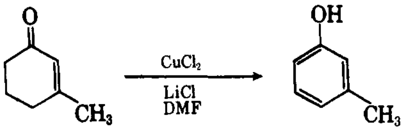
Results

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).



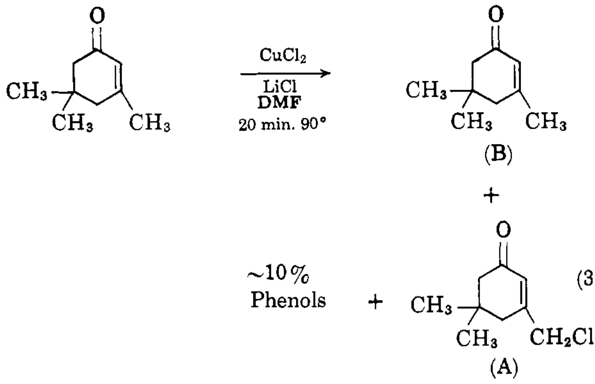
(1)

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.



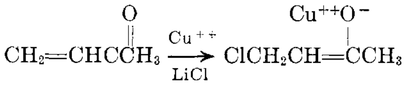
(3)

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



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

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[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.