crystallization from methanol, yellow needles of imenine (**1**, 0.032 g, 35%): mp 206–207°; nmr δ 9.12 (1 H, pair of doublets, J = 8.0 and 2.0 Hz, C_{11} H), 8.57 (1 H, s, C_5 H), 8.56 and 7.80–7.35 (3 H, m, C_{10}, C_9, and C_8 H), 4.22, 4.12, 4.07, 4.02 (each 3 H, s, 4 OCH_3); m/e 351 (M^+), 336 (M − 15), 321 (M − 30); uv λ_{max}^{EtOH} (log ε) 240 (4.30), 275 (4.38), 335 (3.71), 345 (3.71), 434 nm (4.03); $\lambda_{max}^{EtOH-HCl}$ (log ε) 244 (4.07), 290 (4.11), 360 (3.77), 484 nm (3.67). Its ir (KBr) was superimposible upon that of natural imenine and a mixture melting point (206–207°) with the natural base showed no depression.

Registry No.—**1**, 24268-94-8; **5**, 36982-69-1; **6**, 36982-70-4; **7**, 36982-71-5; **7** HCl, 36982-72-6; **8**, 36982-73-7; **8** HCl, 36982-74-8; **9**, 36982-75-9; **11**, 36982-76-0; **12**, 36982-77-1; **13**, 36982-78-2.

Acknowledgment.—We thank the National Institutes of Health for a grant (CA 11445) in support of this work.

The Reaction of Iodobenzene with Nickel Carbonyl in the Presence of *N*-Benzylidene Alkylamine

MEMBO RYANG,* YOSHIHISA TOYODA, SHINJI MURAI, NOBORU SONODA, AND SHIGERU TSUTSUMI

Department of Petroleum Chemistry, Faculty of Engineering, Osaka University, Suita, Osaka, Japan

Received July 10, 1972

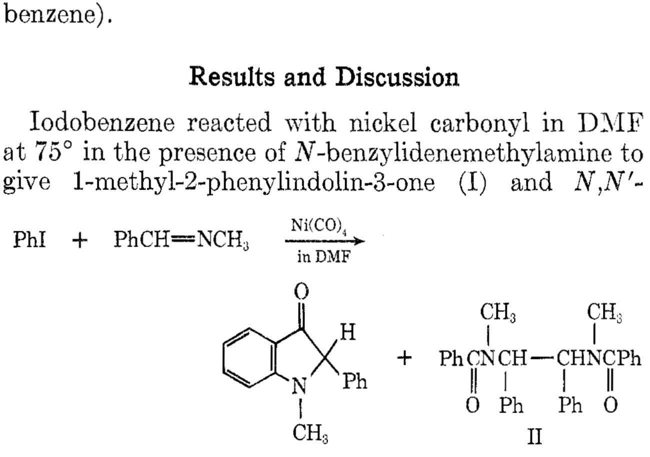
The intermediate benzoylnickel carbonyl iodide, derived from iodobenzene and nickel carbonyl, was reactive toward *N*-benzylidene alkylamine to give 1-alkyl-2-phenylindolin-3-one in *N*,*N*-dimethylformamide (DMF). On the other hand, the similar reaction in benzene solution proceeded *via* a different course to give coupling products of two of the benzoyl groups to an intervening imine double bond.

Organomonohalides react with metal carbonyls to form unstable acyl or alkyl metal carbonyl derivatives, which exhibit unique reactivities toward unsaturated compounds;[1,2] *i.e.*, the addition of the acyl or alkyl group to carbon–carbon double bonds, carbon–carbon triple bonds, and carbon–oxygen double bonds. Herein, although the carbonation and ring closure reactions of Schiff bases or aromatic ketoximes using dicobalt octacarbonyl had been established as a synthetic reaction of phthalimidine derivatives,[3] the reaction of alkyl or acyl metal carbonyl derivatives with imines which contain carbon–nitrogen double bond has not yet been reported.

In this paper we wish to report two types of novel and synthetically useful reactions, *i.e.*, the benzoylation and cyclization of imines to 1-alkyl-2-phenylindolin-3-one (in DMF) and the coupling reaction of two of the benzoyl groups to an intervening imine double bond (in benzene).

Results and Discussion

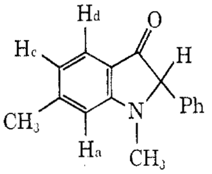
Iodobenzene reacted with nickel carbonyl in DMF at 75° in the presence of *N*-benzylidenemethylamine to give 1-methyl-2-phenylindolin-3-one (I) and *N*,*N'*-dibenzoyl-*N*,*N'*-dimethyl-1,2-diphenylethylenediamine (II) in 28 and 13% yields, respectively.



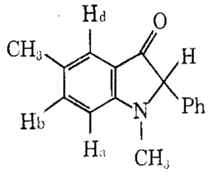
I

II

To determine whether the initial reaction for the formation of I is C attack of the benzoyl group or N attack of the phenyl group, a similar reaction was carried out using *p*-methyliodobenzene instead of iodobenzene. The isolated product (60% yield) was determined to be 1,6-dimethyl-2-phenylindolin-3-one (IIIa)



IIIa



IIIb

by the elemental analysis and ir, mass, and nmr spectra. The nmr spectrum showed the proton H_a signal at τ 3.07 (singlet), the characteristic proton on the α-substituted aromatic nucleus with amine nitrogen, and the proton H_d signal at τ 2.3 (doublet). Herein in the case of the product by the N attack of the *p*-tolyl group to the imine double bond, 1,5-dimethyl-2-phenylindolin-3-one (IIIb), the H_a proton signal should be a doublet and the H_d proton signal a singlet. The formation of IIa strongly suggests that the attack of benzoyl group to the carbon site of the imine double bond occurs first, followed by cyclization, to give the indolinone derivatives as shown in Scheme I. The 1,2-diphenylethylenediamine derivative VI might be formed by the N-attack of benzoyl group to the imine double bond.

This reaction underwent a remarkable solvent effect. When benzene was used as a solvent instead of DMF, the main product was not the indolinone derivative but the coupling product of two of benzoyl group to an intervening imine double bond, *N*-methyl-*N*-(α-phenylphenacyl)benzamide (VII) (53% yield). Similarly the reaction using *N*-benzylideneethylamine gave *N*-ethyl-*N*-(α-phenylphenacyl)benzamide (VIII) in 59% yield. This remarkable solvent effect was considered to be due to the difference of the structure of the intermediate benzoylnickel carbonyl iodide; that is, the benzoylnickel complex was assumed to be monomeric in DMF solution and dimeric in benzene

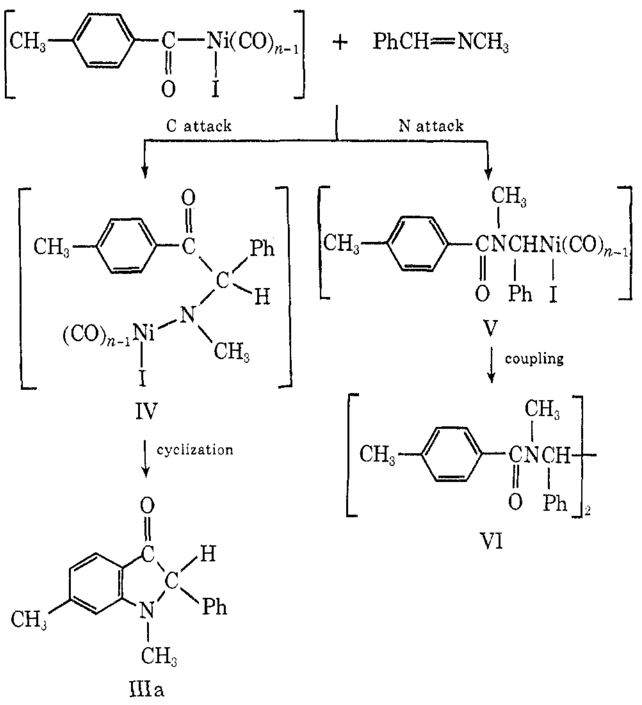
---

[1] M. Ryang, *Organometal. Chem. Rev. A*, **5**, 67 (1970).

[2] M. Ryang and S. Tsutsumi, *Synthesis*, 55 (1971).

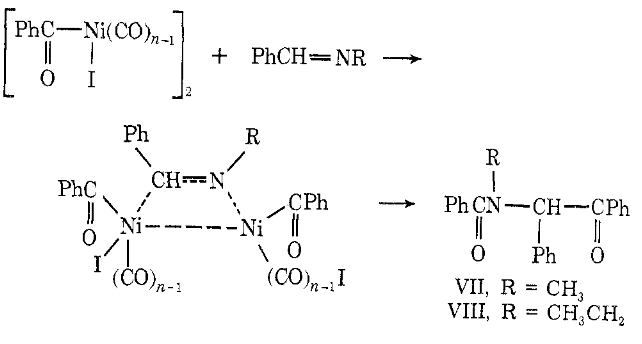
[3] J. Falbe, "Newer Methods of Preparative Organic Chemistry," Vol. VI, Foerst, Ed., Academic Press, New York, N. Y., 1971, p 193.

SCHEME I



solution.[4] Therefore cis insertion of the imine double bond to the benzoyl–nickel bond may proceed in DMF solution. The benzoyl group adds both to the carbon site and the nitrogen site of the imine double bond, thus yielding the second intermediates (IV and V in Scheme I). However, in benzene solution, the less coordinating solvent, the imine coordinates to the nickel atoms of the dimeric benzoylnickel complex and then coupling of two of benzoyl groups occurs to an intervening imine double bond to form VII or VIII (Scheme II).

SCHEME II



Various types of coupling reactions of alkyl or acyl groups using transition metal complexes have been reported. More recently synthetic interest on coupling reactions has been focused on the coupling of alkyl, acyl, or alkoxy groups intervening the unsaturated bond of the third component, such as carbon monoxide, olefins, dienes, acetylenes, and enamines. For example, the following types of new synthetic reactions have been established: formation of carbonates from alkoxycopper and carbon monoxide,[5] synthesis of 1,4-diketones from the reaction of lithium acylnickel carbonylates with acetylenes,[6] and the reaction of α,α'-dibromo ketones with dienes or enamines in the presence of diiron nonacarbonyl.[7,8] The formation of VII and VIII from iodobenzene, *N*-benzylidene alkylamine, and nickel carbonyl in benzene solution presents a new type of coupling reactions of acyl groups, in which the carbon–nitrogen double bond is the third component in coupling.

Furthermore, the formation of indolinone derivatives in DMF solution is also a new type of cyclization reaction and presents a new synthetic route to heterocyclic compounds using organotransition metal complexes.

Experimental Section

The Reaction of Iodobenzene with Nickel Carbonyl in DMF in the Presence of *N*-Benzylidenemethylamine.—Into a 100-ml, three necked flask equipped with a magnetic stirrer, a thermometer, a reflux condensor attached to a gas bubbler with liquid paraffin, and a gas inlet were placed 6.1 g (0.03 mol) of iodobenzene, 4 ml (0.03 mol) of nickel carbonyl, and 3.6 g (0.03 mol) of *N*-benzylidenemethylamine in 50 ml of DMF. The mixture was warmed to 75–80° and was stirred for 22 hr. The reaction mixture was poured into 200 ml of 3 *N* HCl and was extracted with diethyl ether. The ether extract was dried over magnesium sulfate and the ether was evaporated. The precipitated solid was filtered and recrystallized from ethanol to give 0.9 g of white crystals: mp 245–246°; ir 1615 cm^{-1} (CO); nmr τ 7.36 (s, 6 H), 3.09 (s, 2 H), 2.65 ppm (m, 20 H); mass spectrum *m/e* 448 (M$^+$), 224, 105.

Anal. Calcd for $C_{30}H_{28}O_2N_2$: C, 80.33; H, 6.29; N, 6.25. Found: C, 80.50; H, 6.09; N, 6.16.

This compound was confirmed to be *N*,*N'*-dibenzoyl-*N*,*N'*-dimethyl-1,2-diphenylethylenediamine (II) (13% yield). The filtrate was distilled under reduced pressure to give the following fractions: (1) 3.77 g, bp 65–67° (15 mm); (2) 1.32 g, bp 133–155° (0.3 mm); and (3) residual solid, 1.18 g. Fraction 1 was found to consist of nearly equal amounts of benzaldehyde and unreacted iodobenzene by gas chromatographic analysis. Fraction 2 was recrystallized from petroleum ether (bp 30–60°)–benzene to give white crystals: mp 107°; ir 1673 cm^{-1} (CO); nmr τ 7.05 (s, 3 H), 4.69 (s, 1 H), 2.73 (m, 9 H); mass spectrum *m/e* 223 (M$^+$).

Anal. Calcd for $C_{15}H_{13}ON$: C, 80.69; H, 5.87; N, 6.25. Found: C, 80.70; H, 5.77; N, 6.16. This compound was confirmed to be 1-methyl-2-phenylindolin-3-one (I) (28% yield). Residual solid was recrystallized from petroleum ether–benzene to afford white crystals, mp 220°, which was assumed to be α-(*N*-benzoyl-*N*-methyl)aminostilbene (18% yield): ir 1630 (CO), 950 cm^{-1} (C═CH); mass spectrum *m/e* 313 (M$^+$), 105.

The Reaction of *p*-Methyliodobenzene with Nickel Carbonyl in DMF in the Presence of *N*-Benzylidenemethylamine.—A solution of 6.5 g (0.03 mol) of *p*-methyliodobenzene, 3.6 g (0.03 mol) of *N*-benzylidenemethylamine, and 4 ml (0.03 mol) of nickel carbonyl in 50 ml of DMF was stirred at 75–80° for 38 hr. From the reaction mixture, 2.62 g of solids and the following fractions were obtained: (1) 0.74 g, bp 120–160° (1.0 mm); (2) 1.64 g, bp 160–167° (1.0 mm); (3) 0.14 g, bp 167–180° (1.0 mm); and small amounts of residue. The components of solids were isolated by column chromatograph on silica gel. Benzene eluate was recrystallized from petroleum ether–benzene to give white crystals: mp 145°; ir 1670 cm^{-1} (CO); nmr τ 7.66 (s, 3 H), 7.06 (s, 3 H), 4.75 (s, 1 H), 3.07 (s, 1 H), 2.8 (d, 1 H), 2.6 (m, 5 H), 2.3 (d, 1 H); mass spectrum *m/e* 237 (M$^+$). This compound was confirmed to be 1,6-dimethyl-2-phenylindolin-3-one (IIIa) (60% yield). Ethyl ether eluate was recrystallized from ethyl alcohol–ethyl acetate to give small amounts of white crystals, ir 1625 cm^{-1}(CO), mass spectrum *m/e* 238 (P/2), 119 (p-$CH_3C_6H_4CO^+$). This compound was assumed to be *N*,*N'*-di-*p*-toluoyl-*N*,*N'*-dimethyl-1,2-diphenylethylenediamine.

The Reaction of Iodobenzene with Nickel Carbonyl in Benzene in the Presence of *N*-Benzylidenemethylamine.—A solution of

---

[4] I. Rhee, M. Ryang, and S. Tsutsumi, unpublished work.

[5] T. Saegusa, T. Tsuda, K. Isayama, and K. Nishijima, *Tetrahedron Lett.*, 3379 (1968).

[6] Y. Sawa, I. Hashimoto, M. Ryang, and S. Tsutsumi, *J. Org. Chem.*, **33**, 2159 (1968).

[7] R. Noyori, S. Makino, and H. Takaya, *J. Amer. Chem. Soc.*, **93**, 1272 (1971).

[8] R. Noyori, K. Yokoyama, S. Makino, and Y. Hayakawa, *ibid.*, **94**, 1772 (1972).

6.1 g (0.03 mol) of iodobenzene, 3.6 g (0.03 mol) of *N*-benzylidenemethylamine, and 4 ml (0.03 mol) of nickel carbonyl in 50 ml of benzene was stirred at 70–75° for 20 hr. From the reaction mixture, the following fractions were obtained: (1) 0.98 g, bp 90–94° (50 mm); (2) 0.95 g, bp 110–140° (0.4 mm); (3) 0.87 g, bp 140–160° (0.4 mm); and (4) 2.45 g, bp 160–200° (0.4 mm). Fraction 1 was confirmed to be benzaldehyde by gas chromatographic analysis. Fraction 2 and 3 were found to consist of *N*-methylbenzamide and benzil. Fraction 4 was recrystallized from methanol to give white crystals: mp 113°; ir 1695, 1640 cm^{-1} (CO); nmr τ 7.17 (s, 3 H), 2.65 (m, 15 H), 2.05 (broad, 1 H); mass spectrum *m/e* 329 (M$^+$), 224, 105. *Anal.* Calcd for $C_{22}H_{19}O_2N$: C, 80.36; H, 5.69; N, 4.30. Found: C, 80.22; H, 5.81; N, 4.25. This compound was confirmed to be *N*-methyl-*N*-(α-phenylphenacyl)benzamide (VII) (53% yield), the coupling product of two of benzoyl group intervening *N*-benzylidenemethylamine.

The Reaction of Iodobenzene with Nickel Carbonyl in Benzene in the Presence of *N*-Benzylideneethylamine.—A solution of 6.1 g (0.03 mol) of iodobenzene, 6 g (0.045 mol) of *N*-benzylideneethylamine, and 4 ml (0.03 mol) of nickel carbonyl in 50 ml of benzene was stirred at 70–75° for 24 hr. From the reaction mixture, the following fractions were obtained: (1) 1.0 g, bp 30–35° (0.5 mm); (2) 1.54 g, bp 124–153° (0.6 mm); and (3) 2.91 g, bp 154–210° (0.6 mm). Fraction 1 was confirmed to be benzaldehyde. Fraction 2 was confirmed to consist of 87 parts of *N*-benzyl-*N*-ethylbenzamide and 13 parts of *N*-ethylbenzamide. Fraction 3 was recrystallized from petroleum ether–benzene to afford white crystals: mp 103°; ir 1685, 1628 cm^{-1} (CO); mass spectrum *m/e* 333 (M$^+$), 228, 105. *Anal.* Calcd for $C_{23}H_{21}O_2N$: C, 80.69; H, 5.94; N, 4.08. Found: C, 80.44; H, 6.16; N, 3.81. This compound was confirmed to be *N*-ethyl-*N*-(α-phenylphenacyl)benzamide (VIII) (59% yield).

Registry No.—I, 36917-63-2; II, 36917-64-3; IIIa, 36917-65-4; VII, 36917-66-5; VIII, 36895-14-4; iodobenzene, 591-50-4; nickel carbonyl, 13463-39-3; *N*-benzylidene, methylamine 622-29-7; α-(*N*-benzoyl-*N*-methyl)aminostilbene, 16151-51-2; *p*-methyliodobenzene, 624-31-7; *N*-benzylideneethylamine, 6852-54-6.

The Group VI Metal Carbonyl Catalyzed Reaction of Ethers and Acid Halides

HOWARD ALPER* AND CHE-CHENG HUANG

Department of Chemistry, State University of New York at Binghamton, Binghamton, New York 13901

Received August 18, 1972

The reaction of acyclic and cyclic ethers with acid halides in the presence of catalytic quantities of Group VI metal carbonyls [$M(CO)_6$, where M = Cr, Mo, W] was investigated. The catalytic order of effectiveness was found to be $Mo(CO)_6 > W(CO)_6 > Cr(CO)_6$ with $Mo(CO)_6$ being a very useful catalyst for the reaction. The group VA substituted molybdenum carbonyls, $EMo(CO)_5$ [E = $(C_6H_5)_3P$, $(C_6H_5)_3As$] and *cis*-$[(C_6H_5)_3P]_2Mo(CO)_4$, are also good catalysts for the reaction. These catalytic reactions can be carried out either thermally or photochemically (at room temperature). The effects of temperature, of oxygen, and of variation of the halogen in the acid halide on the thermal reaction are noted. Stereochemical studies show that the reaction occurs with partial or complete retention, or net inversion of configuration, subject to the nature of the ether. An ionic mechanism is proposed for these reactions.

Considerable interest has developed recently in the use of Group VI metal carbonyls [$M(CO)_6$, M = Cr, Mo, W] as catalysts[1-8] and as stoichiometric reagents[9-11] for organic synthesis. This paper is concerned with the catalysis of the reaction of ethers and acid halides[12] by these metal carbonyls. The primary objectives of this study were the effectiveness of Group VI metal carbonyls as catalysts compared to other catalysts for the ether–acid halide reaction; the relative catalytic effectiveness within Group VI and possible correlations with the metal–carbon bond strength;[13,14] and the stereochemistry and possible mechanism(s) for the reaction.

Results and Discussion

Acyclic Ethers.—Refluxing the acyclic ethers, neat or in hexane or isooctane solution, with acid chlorides in the presence of molybdenum hexacarbonyl gave esters, organic chlorides, and, in some instances, alkenes.

$$ROR + R'COCl \xrightarrow{Mo(CO)_6} RCl + R'COOR$$

The results are listed in Table I. For unsymmetrical ethers, the alkyl chloride formed is that derived from the more highly substituted alkoxy carbon atom. Only in the case of benzoin methyl ether was a sluggish reaction observed, probably owing to the presence of the electron-attracting benzoyl group in the reactant ether. When dehydrohalogenation occurs, Saytzeff's rule is usually, but not always, followed. Olefins produced in some of these reactions do not arise from $Mo(CO)_6$-catalyzed dehydrohalogenation of an alkyl chloride, since, for example, 2-chlorooctane was inert to $Mo(CO)_6$ when refluxed in hexane for 1 day.

The alkyl aryl ether, *n*-butyl phenyl ether, reacted with acetyl chloride in the presence of $Mo(CO)_6$ to give only traces of *o*- and/or *p*-*n*-butoxyacetophenone. Here, complexation of the benzene ring of the reactant ether with molybdenum carbonyl may give the less active arene–$Mo(CO)_3$ catalyst.

Cyclic Ethers.—A number of cyclic ethers were subjected to acid halide treatment in the presence of

(1) J. Drapier, A. J. Hubert, and P. Teyssie, *J. Chem. Soc., Chem. Commun.*, 484 (1972).

(2) R. D. Smetana, U. S. Patent 3,657,251 (1972); *Chem. Abstr.*, **77**, 5355u (1972).

(3) M. N. Sheng and J. G. Zajacek, *J. Org. Chem.*, **33**, 588 (1968).

(4) M. N. Sheng and J. G. Zajacek, *Advan. Chem. Ser.*, **No. 76**, 418 (1968).

(5) C. H. Bamford, G. C. Eastmond, and F. J. T. Fildes, *Chem. Commun.*, 144, 146 (1970), and references cited therein.

(6) H. Kolshorn, H. Meier, and E. Muller, *Tetrahedron Lett.*, 1589 (1972), and references cited therein.

(7) H. Ulrich, B. Tucker, and A. A. R. Sayigh, *ibid.*, 1731 (1967).

(8) R. D. Raap and I. J. Borowitz, *Chem. Commun.*, 1202 (1969).

(9) H. Alper, *Organometal. Chem. Syn.*, **1**, 69 (1971).

(10) H. Alper, *Angew. Chem., Int. Ed. Engl.*, **8**, 677 (1969).

(11) E. Lindner and G. Vitzthum, *ibid.*, **8**, 518 (1969).

(12) R. L. Burwell, Jr., *Chem. Rev.*, **54**, 615 (1954).

(13) D. R. Lloyd and E. W. Schlag, *Inorg. Chem.*, **8**, 2544 (1969).

(14) R. B. King, *Inorg. Nucl. Chem. Lett.*, **5**, 905 (1969).