Chloramine	Entry	Conditions	Product	% yield[a]
(1)	A	HOAc, H_2SO_4, 0°, 1 hr, N_2	3	44
	B	HOAc, H_2SO_4, $h\nu$, 35°, 2.5 hr	3	Trace
	C	Ether, $h\nu$, 35°, 17 hr	4	23[b]
	D	CH_3NO_2, H_2SO_4, 0°	3	26
	E	PE[c]–benzene, room temp, dark, 1 day	4	36[b]
	F	CH_3CN, room temp, dark, 2 days	4	50
	G	MeOH, $AgNO_3$, reflux, 4.5 hr	4	22
	H[d]	Toluene, $AgBF_4$, room temp, dark, 1 day	4	10
$(n\text{-}C_4H_9)_2NCl$ (2)	I	PE[c]–benzene, room temp, dark, 3 days	4	51
	J	CH_3CN, room temp, dark, 3 days	4	8

[a] Based on reacted indole. [b] Glc analysis. [c] Petroleum ether. [d] We thank K. S. Bhandari for this experiment.

reported herein show, however, that the chloramines act mainly as electrophilic chlorinating agents[2] in reactions with indole under a variety of conditions. Analogous behavior has been found recently in the reaction of indole with *N,N*-dichlorourethan.[6,7] Nevertheless, our work provides a facile alternate synthesis of 3-chloroindole (4).[8]

The results are summarized in Table I. The application of the strongly acidic Hofmann–Loeffler–Freytag conditions[4] to the reaction of indole with 1 gave poor yields of 3,3-dichlorooxindole (3) (entries A, B, and D) in agreement with the known ready oxidizability of indole by such reagents.[9] Treatment of indole with 1 in the presence of silver salts under conditions which are known to generate nitrenium ions[5] gave poor yields of 4, irrespective of the nature of the anion (entries G and H). Finally, when the reaction was carried out in the absence of metal or acidic catalysts in the dark for extended periods of time, fair to good yields of 4 were obtained (entries E and F). The lower yield of 4 obtained in the reaction of indole with *N*-chlorodibutylamine (2) in acetonitrile (entry J) is due to the decomposition of 2 to *n*-dibutylamine hydrochloride (30%) in the more polar solvent.

Cl
Cl
=O
N
H
3

Cl
N
H
4

Experimental Section

Melting points were determined on a Fisher-Johns apparatus and are uncorrected. Infrared spectra were recorded with a Beckman IR-5 spectrophotometer. Ultraviolet spectra were obtained with a Beckman DB-G spectrophotometer. A Jeol C-60 instrument was used for recording nmr spectra. Gas-liquid chromatography (glc) was carried out on an Aerograph Autoprep Model 700 with a 10 ft × ⅜ in. column of 10% SE-30 silicone gum rubber on 60–80 mesh Chromosorb W. The photolyses were performed in a Rayonet Reactor in quartz vessels using 3500 Å lamps. Silica gel (Brinkmann, 0.05–0.20 mm) was used for chromatography. Reagent grade acetonitrile and methanol were used without further purification. Reagent grade benzene and petroleum ether (60–80°) were dried and distilled before use.

(6) T. A. Foglia and D. Swern, *J. Org. Chem.*, **33**, 4440 (1968).

(7) J. M. Muchowski, *Can. J. Chem.*, **48**, 422 (1970). We thank Dr. Muchowski for a preprint and for discussion.

(8) J. C. Powers, *J. Org. Chem.*, **31**, 2627 (1966).

(9) R. L. Hinman and E. R. Shull, *ibid.*, **26**, 2339 (1961); G. F. Smith and A. E. Walters, *J. Chem. Soc.*, 940 (1961).

Reaction of Indole with *N*-Chloropyrrolidine (1). A. In Sulfuric Acid–Acetic Acid.—A mixture of 4.4 ml of 98% sulfuric acid and 15 ml of glacial acetic acid was stirred under nitrogen in an ice bath for 10 min. An ethereal solution of 1 (9 ml, 9 mmol) was then added and stirring was continued for another 15 min. Indole (1.05 g, 9 mmol) was added in small portions and the resulting green mixture was stirred for 1 hr. It was then poured into 200 ml of ice water and extracted with chloroform. The chloroform extracts were washed with water and dried (MgSO₄). Evaporation of solvent gave 3,3-dichlorooxindole (3), 0.8 g (44%), which was characterized by identical ir, nmr, melting points, and mixture melting point with an authentic sample.[10]

B. In Acetonitrile.—A mixture of 560 mg (4.8 mmol) of indole in 10 ml of acetonitrile and 8 ml (4.8 mmol) of 1 in ether was stirred at room temperature in the dark for 2 days. The solvent was evaporated and the resulting residue was dissolved in methylene chloride and washed three times with saturated sodium bicarbonate solution. The methylene chloride extract yielded after drying (Na₂SO₄) 990 mg of an oil which was chromatographed. Elution with petroleum ether–benzene (1:1) followed by sublimation gave 386 mg (50%) of 4.

A blank run showed that 1 was stable under the above conditions for at least 5 days as determined by sodium thiosulfate titration.

(10) A. Hantzsch, *Ber.*, **54B**, 1221 (1921).

Synthetic Reactions by Complex Catalysts.
XVIII. The Reaction of Azide with Isocyanide
by Iron Carbonyl Catalyst.
A New Route to Carbodiimide

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This note describes the iron carbonyl catalyzed reaction of an azide with isocyanide, which provides a new method for the preparation of the unsymmetrical carbodiimide (eq 1). In the absence of catalyst, no reac-

$$\underset{\text{I}}{RN_3} + \underset{\text{II}}{R'N{\equiv}C{:}} \xrightarrow{\text{catalyst}} \underset{\text{III}}{R{-}N{=}C{=}N{-}R'} + N_2 \quad (1)$$

tion occurs; azide and isocyanide were recovered almost quantitatively from the reaction system. In the

TABLE I

REACTION OF AZIDE WITH ISOCYANIDE[a]

RN₃	Mmol	R'NC	Mmol	Catalyst	Mmol	R—N=C=N—R'	Yield,[b] %
c-C₆H₁₁N₃	10	t-C₄H₉NC	36	Fe(CO)₅	0.5	c-C₆H₁₁—N=C=N—C₄H₉-t	60
c-C₆H₁₁N₃	10	c-C₆H₁₁NC	28	Fe(CO)₅	0.5	c-C₆H₁₁—N=C=N—C₆H₁₁-c	48
c-C₆H₁₁N₃	10	C₆H₅NC	36	Fe(CO)₅	0.5	c-C₆H₁₁—N=C=N—C₆H₅	51
c-C₆H₁₁N₃	10	c-C₆H₁₁NC	37	Cu₂O[c]	1.0	c-C₆H₁₁—N=C=N—C₆H₁₁-c	2
c-C₆H₁₁N₃	10	c-C₆H₁₁NC	28	None		No reaction	

[a] Reactions were carried out at 90° for 24 hr under nitrogen atmosphere. [b] Product yield is based upon the amount of azide. [c] A considerable amount of tar was produced in this reaction.

presence of iron pentacarbonyl, the reaction proceeds smoothly. Cuprous oxide, which has been employed as an effective catalyst in the reactions of isocyanide[1] and of the azide,[2] exhibits a poor catalytic activity in the present reaction. The results of the azide–isocyanide reaction are shown in Table I. It is important to note that only the carbodiimide of the structure as indicated by III is produced and other carbodiimides having structures of R—N=C=N—R and R'—N=C=N—R' are not formed.

The formation of carbodiimide may be formulated as being the combination of isocyanide and nitrene, which are characterized by lone-pair electrons attached to carbon and nitrogen, respectively. These two species[3,4] are known to form coordination complexes with metal carbonyls. Ligand exchange of iron pentacarbonyl with isocyanide is considered possible in the present reaction conditions.[3a] Therefore, it can be assumed that the isocyanide complex reacts either with azide or nitrene.

Concerning the isocyanide–nitrene reaction, a reaction of cyclohexyl isocyanide with N-chloro-p-toluenesulfonamide in alkaline methanol has been reported,[5] in which a mechanism of the reaction of isocyanide with an intermediate of p-toluenesulfonyl-nitrene was suggested as one of possible courses.

The reaction found in this study can be compared with the metal carbonyl catalyzed condensation of 2 mol of isocyanate, which also produces carbodiimide (eq 2).[6] The condensation of isocyanate has been

$$2R—N=C=O \longrightarrow R—N=C=N—R + CO_2 \quad (2)$$

explained by the intermediate production of metal isocyanide complex (eq 3) and the subsequent reaction

$$Me(CO) + R—N=C=O \longrightarrow Me(CN—R) + CO_2 \quad (3)$$

of this complex with the second molecule of isocyanate (eq 4). In this connection, the azide–isocyanide

$$Me(CN—R) + R—N=C=O \longrightarrow$$
$$R—N=C=N—R + Me(CO) \quad (4)$$

reaction by iron carbonyl catalyst in the present study might be regarded as the reaction of isocyanide with isocyanate which is formed intermediately from nitrene and the carbon monoxide ligand. This possibility, however, was not supported by a reference experiment in which an equimolar mixture of cyclohexyl azide and iron pentacarbonyl was heated. The gaseous mixture evolved from the heat treated mixture consisted of nitrogen and carbon monoxide. No carbon dioxide was detected. Furthermore, neither cyclohexyl isocyanate nor dicyclohexylcarbodiimide was detected in the reaction mixture. Consequently, the azide–isocyanide reaction is not depicted by eq 3 and 4. Elucidation of the features of this interesting reaction awaits further study.

Experimental Section

Reaction of Cyclohexyl Azide (I) with tert-Butyl Isocyanide (IIa).—To a mixture of IIa (36 mmol) and Fe(CO)₅ (0.5 mmol), I (10 mmol) was added dropwise during 15 min at room temperature under nitrogen atmosphere. The reaction mixture was then heated for 24 hr at 90°. From the reaction mixture the insoluble part was removed by filtration, and the filtrate was distilled *in vacuo* to give a distillate (1.1 g) boiling at 63 ∼ 65° (2 mm). The distillate was subjected to glpc analysis. The product was shown to be tert-butylcyclohexylcarbodiimide (IIIa, 60%). Compound IIIa was identified by ir and nmr spectra and elemental analysis: ir of IIIa (neat) $\nu_{N=C=N}$ 2160 cm⁻¹ (vs); nmr (CDCl₃) τ 6.50∼7.05 (1 H, broad singlet), 7.85∼9.0 (10 H, broad multiplet), and 8.70 (9 H, singlet).

Anal. Calcd for C₁₁H₂₀N₂: C, 73.28; H, 11.18; N, 15.54. Found: C, 73.55; H, 11.26; N, 15.82.

Reaction of Cyclohexyl Azide (I) with Cyclohexyl Isocyanide (IIb).—The reaction was carried out by a similar procedure. The product was dicyclohexylcarbodiimide (IIIb, 48%). IIIb was identified by comparison of ir and nmr spectra and the glpc retention time with those of the authentic sample.

The reaction of cyclohexyl azide (I) with phenyl isocyanide (IIc) was carried out by a similar procedure. The product, N-cyclohexyl-N-phenylcarbodiimide (IIIc, 51%), was identified by comparison of ir spectrum and the glpc retention time with those of the authentic sample.

Reaction of Cyclohexyl Azide (I) with Iron Pentacarbonyl (IV).—A mixture of I (10 mmol), IV (10 mmol), and acetonitrile (5 ml) in a 50-ml stainless steel pressure tube was heated at 80° for 15 hr. After the reaction, the gaseous products were trapped and analyzed by glpc with a column of silica gel (column temperature 40° for carbon dioxide, −78° for nitrogen and carbon monoxide). Nitrogen (7.5 mmol, 75%) and carbon monoxide (1.3 mmol) were produced. The nonvolatile part of reaction mixture was analyzed by glpc. Dicyclohexylcarbodiimide (IIIb) and cyclohexylisocyanate could not be detected. The nitrene–iron carbonyl complex[4] may have been produced.

(1) (a) T. Saegusa, Y. Ito, S. Kobayashi, K. Hirota, and H. Yoshioka, *Tetrahedron Lett.*, 6121 (1966); *Bull. Chem. Soc. Jap.*, **42**, 3535 (1969). (b) T. Saegusa, Y. Ito, S. Kobayashi, K. Hirota, and N. Takeda, *Can. J. Chem.*, **47**, 1217 (1969). (c) T. Saegusa, S. Kobayashi, Y. Ito, K. Hirota, and Y. Okumura, *Bull. Chem. Soc. Jap.*, **41**, 1638 (1968).

(2) (a) H. Kwart and A. A. Kahn, *J. Amer. Chem. Soc.*, **89**, 1950 (1967); **89**, 1951 (1967). (b) T. Saegusa, Y. Ito, and T. Shimizu, to be published in *J. Org. Chem.*

(3) (a) W. Hieber and D. V. Pigenot, *Chem. Ber.*, **89**, 193 (1956). (b) L. Malatesta, *Progr. Inorg. Chem.*, **1**, 283 (1959).

(4) M. Dekker and G. R. Knox, *Chem. Commun.*, 1243 (1967).

(5) W. Aumüller, *Angew. Chem.*, **75**, 857 (1963).

(6) H. Ulrich, B. Tucker, and A. A. R. Sayigh, *Tetrahedron Lett.*, 1731 (1967).

Registry No.—Carbodiimide (R = c-C₆H₁₁; R' = t-C₄H₉), 1202-53-5; carbodiimide (R = R' = c-C₆H₁₁), 538-75-0; carbodiimide (R = c-C₆H₁₁; R' = Ph), 3878-67-9; iron pentacarbonyl, 13463-40-6.