ethereal layer and the extracts turning dark. The extracts were acidified with hydrochloric acid and extracted with ether, and the ether extracts were dried. Evaporation of the ether layers gave a small amount of a residue which did not contain any II.

Dimethyl Ester of II.—To 25 ml of an ethereal solution of about 0.2 g of diazomethane[17] was added dropwise a solution of 0.42 g (0.0016 mole) of II in 10 ml of ether. After being stirred at room temperature for 3 days, the mixture was filtered and evaporated *in vacuo* to give a tan solid which, after recrystallization in carbon tetrachloride, gave 0.2 g of white crystals, mp 138–139°. Vapor phase chromatography on a fluorosilicone column showed one component which is believed to be the *cis* isomer. The infrared spectrum (halocarbon mull) shows expected sharp peaks at 2955, 1755, 1595, and 1435 cm^{-1}.

Anal. Calcd for $C_9H_6Cl_6O_4$: C, 27.66; H, 1.55; Cl, 54.42. Found: C, 27.37; H, 1.41; Cl, 54.14.

Oxidation of V with Nitric Acid.—A mixture of 1.9 g (0.005 mole) of V and 15 ml of 70% nitric acid was heated on a steam bath, while being rapidly stirred, for 1 hr. When the mixture was allowed to cool slowly to room temperature without stirring, white crystals appeared which were filtered and washed with cold water. The filtrate was extracted several times with ether, and the combined ether extracts were washed with water before they were dried over anhydrous magnesium sulfate. Evaporation of the ether gave an off-white material which was washed with hot carbon tetrachloride to give, along with the white crystals, 0.55 g of II, as shown by the infrared spectrum, melting point, mixture melting point, and thin layer chromatography.

Oxidation of X with Nitric Acid.—In a similar fashion to the preceding experiment, oxidation of X with nitric acid gave II.

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Carbonylation of Amines in the Presence of Palladium(II) Chloride. A New Route to Isocyanates

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Despite the availability of numerous methods for the preparation of isocyanates, the most widely used route to these important compounds is treatment of a primary amine or its salt with phosgene.[1] In this reaction, introduction of the carbonyl group proceeds stepwise, elimination of the first mole of HCl leading to formation of the carbamyl chloride from which the isocyanate is generated by elimination of a second mole of HCl.

It has now been found that a more direct preparation of isocyanates is effected by combining primary aliphatic or aromatic amines with carbon monoxide in the presence of $PdCl_2$. The reaction proceeds readily under rather mild conditions (Table I) and is accompanied by reduction of $PdCl_2$ to metal (eq. 1).

$$RNH_2 + CO + PdCl_2 \longrightarrow RNCO + Pd + 2HCl \quad (1)$$

TABLE I

CARBONYLATION OF AMINES IN THE PRESENCE OF $PdCl_2$

Amine	Pressure, atm.	Temp., °C.	Reaction time, hr.	Isocyanate yield, mole %
n-Butylamine	1.4	65	48	49.2
Aniline	1.4	80	96	53.4
Aniline	1.0	85	21	68.0
Toluene-2,4-diamine	1.0	85	2.5	9.2

While detailed information concerning the mechanism of this new and interesting reaction is lacking to date, several possible reaction paths can be eliminated from further consideration. For example, formation of formamides from amines and carbon monoxide in the presence of a number of transition metal salts and carbonyls has been reported.[2] One might, therefore, speculate that isocyanate formation in the present case is preceded by production of formamides followed by dehydrogenation, the latter step leading to reduction of $PdCl_2$ (eq. 2 and 3). Since reduction of

$$RNH_2 + CO \longrightarrow RNHCHO \quad (2)$$

$$RNHCHO + PdCl_2 \longrightarrow RNCO + Pd + 2HCl \quad (3)$$

$PdCl_2$ as well as the presence of isocyanates in the reaction mixtures was observed shortly after the combination of reagents, and the presence of formamides was not detected at any time, it was assumed that reaction 3, if it had occurred, was quite fast. However, contact of formanilide with $PdCl_2$, under conditions leading to fairly rapid formation of phenyl isocyanate from aniline and CO, resulted in no reduction of $PdCl_2$ or isocyanate production in 240 hr. It is clear, therefore, that reaction 3 does not occur and that production of isocyanates does not proceed through intermediate formation of formamides.

It is also clear that isocyanate formation is not due to *in situ* phosgene formation from $PdCl_2$ and CO. In the absence of amine, no reduction of $PdCl_2$ by CO was observed during extended periods of time at temperatures ranging from 40 to 200°.

The readily visible reduction of Pd(II) to metal which accompanies formation of isocyanates has also been noted in the previously reported vinylation in which olefins react with nucleophiles in the presence of $PdCl_2$.[3] The reaction is independent of the order in which amines or CO are added to $PdCl_2$ and, moreover, has been observed when amines are added to $(PdCOCl_2)_2$ or CO to $Pd(RNH_2)_2Cl_2$. Mechanistically then, it is possible that amines and carbon monoxide combine in a palladium complex containing both species and that decomposition of this material leads to isocyanate formation.

Experimental Section

Liquid reagents were freshly distilled and stored over molecular sieves. Solids were vacuum dried at 100°. Infrared and vapor phase chromatographic analyses are based on calibrations with authentic materials.

***n*-Butyl Isocyanate.**—A mixture of $PdCl_2$ (4.43 g., 25 mmoles) and Na_2HPO_4 (5.89 g., 41 mmoles) was evacuated at 95° for 16 hr. in a 250-ml. round-bottom flask connected to a manifold.

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[2] F. Calderazzo, *Inorg. Chem.*, **4**, 293 (1965).

[3] E. W. Stern and M. L. Spector, *Proc. Chem. Soc.*, 370 (1961).

After cooling to room temperature, 50 ml. of dry 1,2-dimethoxyethane was injected through a side arm closed by a rubber serum cap, followed by 2.61 ml. (25 mmoles) of *n*-butylamine dissolved in 20 ml. of 1,2-dimethoxyethane. The mixture was stirred magnetically for 1 hr. Carbon monoxide was then admitted to a pressure of 1.4 atm. After 1 hr., the temperature was increased to 65°. Decreases in pressure were noted, and the pressure was maintained at approximately 1.4 atm. by addition of CO. Samples of the reaction mixture were withdrawn periodically and analyzed by vapor phase chromatography and infrared spectroscopy. The presence of *n*-butyl isocyanate was detected after 1.75 hr. at 65°, and successive samples were shown to contain increasing amounts of this material. Solids in the reaction flask became progressively blacker, indicating reduction of $PdCl_2$ to metal.

After 48 hr. the mixture was cooled to room temperature. Analysis of a sample withdrawn at that time showed that the liquid phase contained 2 vol. % of *n*-butyl isocyanate, constituting a yield of 49.2 mole % (based on amine).

The mixture was then treated with excess *n*-butylamine and stirred for 0.5 hr. Infrared analysis confirmed the conversion of isocyanate present to di-*n*-butylurea. The mixture was filtered and the solids were washed with 1,2-dimethoxyethane. The solvent was stripped under vacuum from the combined filtrate and washings. The residue was dissolved in ether, extracted with aqueous NaCN, dried over $MgSO_4$, filtered, and stripped. The solid residue (2.59 g.) was recrystallized from ethanol-ether, yielding 2.34 g. of white crystals shown to be identical in melting point and infrared spectrum with an authentic sample of di-*n*-butylurea. The total yield of urea (based on $PdCl_2$) was 54.4 mole %.

Phenyl Isocyanate. Procedure A.—The procedure used was essentially that employed in the preparation of *n*-butyl isocyanate. After the addition of 2.27 ml. (25 mmoles) of aniline in 20 ml. of 1,2-dimethoxyethane, the mixture was stirred at an initial CO pressure of 1.1 atm. After 1.5 hr. at room temperature, the presence of phenyl isocyanate was detected by infrared spectroscopy. The mixture was then stirred at 65° for 24 hr. and at 80° for 96 hr. During this time, reduction of $PdCl_2$ was again observed and the presence of increasing amounts of phenyl isocyanate was noted. Carbon monoxide was absorbed continuously during the reaction period, and the pressure was maintained at 1.4 atm. by periodic additions of CO. Final vapor phase chromatographic analysis of the liquid phase showed a phenyl isocyanate content of 2.1 vol. %, constituting a 53.4 mole % yield.

Treatment of the mixture with excess aniline followed by the same procedure as before led to the isolation of 3.7 g. of solid which, when recrystallized from ethanol yielded 2.67 g. (50.2 mole % based on $PdCl_2$) of diphenylurea, identical with authentic material.

Procedure B.—To a 250-ml. flask fitted with a dropping funnel, a Vibromix stirrer, a gas inlet, and a reflux condenser, were added 4.43 g. (25 mmoles) of $PdCl_2$ and 5.89 g. (41 mmoles) of Na_2HPO_4. Dry nitrogen was passed through the flask for 16 hr. after which 60 ml. of dry 1,2-dimethoxyethane was added. Agitation of the mixture was then begun and the nitrogen flow was replaced with CO at a rate of 17,000 cc./hr. The solvent was brought to reflux and 2.27 ml. (25 mmoles) of aniline in 40 ml. of 1,2-dimethoxyethane was added dropwise over a period of 3 hr. Carbon monoxide flow and temperature were maintained for an additional 18 hr. Solids in the flask assumed a black coloration during this time, and analysis of periodic samples indicated the presence of phenyl isocyanate. After the addition of sufficient 1,2-dimethoxyethane to restore the liquid volume to its original level, the mixture was shown to contain 1.8 vol. % of phenyl isocyanate by vapor phase chromatographic analysis, constituting a yield of 68.0 mole %.

Toluene 2,4-Diisocyanate.—The procedure followed was essentially procedure B used for phenyl isocyanate. The reaction was carried out in 100 ml. of 1,2-dimethoxyethane, and the mixture was agitated under nitrogen for 24 hr. and under CO for 24 hr. prior to the dropwise addition of 1.80 g. (15 mmoles) of toluene-2,4-diamine (recrystallized four times from benzene) in 100 ml. of 1,2-dimethoxyethane (this solution having been flushed with nitrogen for 48 hr.) over a period of 2 hr. Formation of metallic palladium was observed during the latter period. Agitation was continued for an additional 0.5 hr. at which time vapor phase chromatographic analysis indicated a yield of 9.6 mole % of toluene 2,4-diisocyanate (based on the diamine).

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Organic Disulfides and Related Substances. XV. Attempted Syntheses of Mercapto Disulfides[1]

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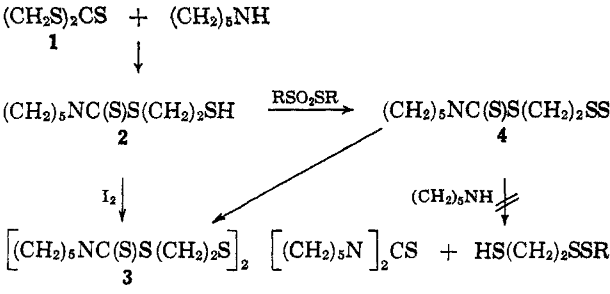
To our knowledge, only one mercapto disulfide actually has been isolated,[2] although some others either have been identified in solution or suggested to be present. Since mercapto disulfides contain two mutually reactive groups, more information on their characteristics would be of much interest, even though thiol–disulfide interchange reactions[3] presumably would lead to polymer in the absence of careful handling. This paper reports results worthy of record obtained during two approaches to synthesis of mercapto disulfides, which were unsuccessful although based on reasonable analogies.

As shown by eq 1, one approach depended upon cleavage of ethylene trithiocarbonate (**1**) with piperidine, followed by thioalkylation of the resulting thiol (**2**) to give the disulfide **4**, with the final step to be cleavage of the thiocarbamoyl moiety of **4** with piperidine.



(1)

$R = (CH_2)_2NHAc$

Reactions of ethylene trithiocarbonate with secondary amines have been studied before. Delaby and co-workers believed their first products to be thiols (as in eq 1);[4] they later identified these as disulfides but were able to obtain thiols under modified conditions.[5] Durden and co-workers obtained only disulfides,[6] and Johnston and co-workers obtained neither

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[1] This investigation was supported by the U. S. Army Medical Research and Development Command, Department of the Army, under Research Contract No. DA-49-193-MD-2030. Paper XIV: T. F. Parsons, J. D. Buckman, D. E. Pearson, and L. Field, *J. Org. Chem.*, **30**, 1923 (1965).

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