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A NEW TYPE OF ORGANOMERCURIC COMPOUND FROM THE REACTION OF ISOCYANIDES WITH MERCURIC ACETATE

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Summary

Aromatic isocyanides react with mercuric acetate to give a new type of organomercuric compound. The structure of one of these was determined by X-ray analysis. The hydrolysis of these products gave acetamide derivatives. t-Butyl and cyclohexyl isocyanide reacted with mercuric acetate in the same manner. However, in the latter cases the corresponding organomercuric compound was too unstable to isolate and the acetamide derivative was isolated instead.

Introduction

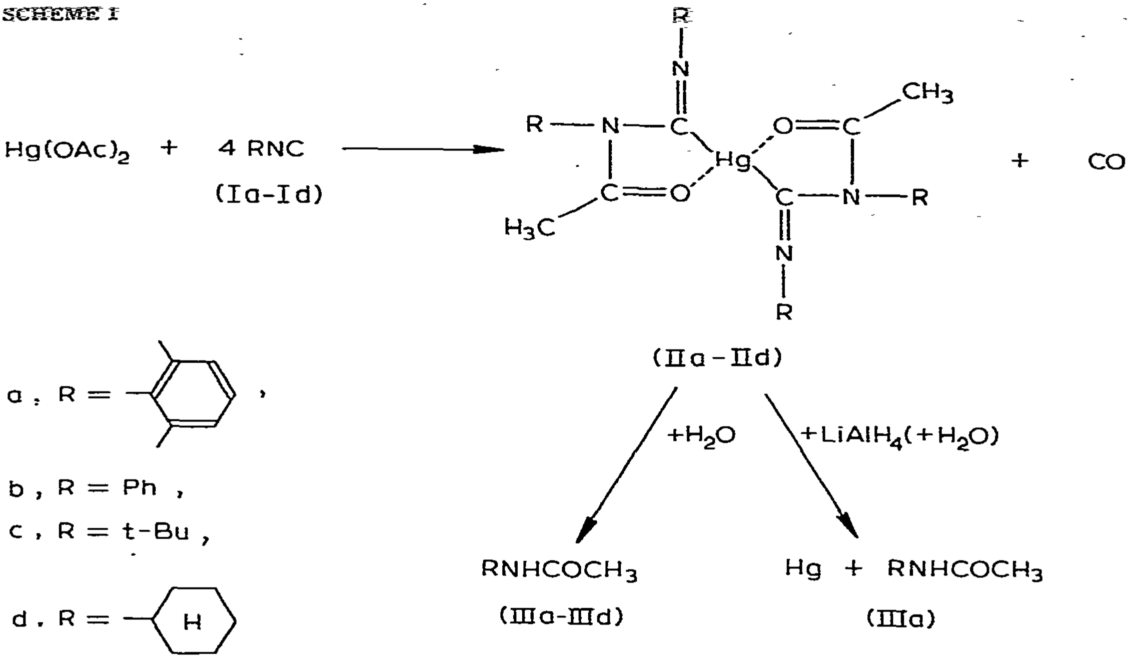
Isocyanides react with various metal ions to form isocyanide—metal complexes. Many interesting reactions of such complexes have been reported recently. However, little has been reported about the reaction of isocyanides with mercuric compounds. Previously we reported that isocyanides react with mercuric salts and nucleophiles in the sense of a redox reaction [1—3]. The redox reaction of isocyanides with mercuric acetate in the presence of water, amines, ethanol and phenol gave ureas and urethanes in good yields [1]. In the absence of nucleophiles, a redox reaction did not take place and a new organomercuric compound was formed. In this paper, we wish to report the synthesis and the reactions of such an organomercuric compound. Its crystal structure has been determined by the X-ray diffraction method.

Results and discussion

Reaction of isocyanides with mercuric acetate

Mercuric acetate and four molar equivalents of 2,6-dimethylphenyl isocyanide (Ia) in dry tetrahydrofuran (THF) were heated at reflux. A grayish white precipitate of mercurous acetate was formed and a white crystalline organomercuric compound (IIa) was isolated from the reaction mixture in 26% yield (Scheme 1). Compound IIa was soluble in THF and insoluble in ether. Its IR spectrum shows

SCHEME I



absorptions at 1660 and 1648 cm^{-1} due to ν(C=O) and ν(C=N), but no absorption at 3200 cm^{-1} (ν(NH)). The NMR spectrum of IIa shows that it is composed of one mole of mercuric acetate and four moles of Ia. The structure of IIa was finally determined by X-ray analysis. The mass spectrum and elemental analysis of IIa agree with the structure determined. In the reaction of Ia with mercuric acetate, the evolution of carbon monoxide was confirmed by gas chromatography.

The hydrolysis of IIa in aqueous THF at reflux gave *N*-2,6-dimethylphenyl acetamide (IIIa) in 94.5% yield, and an unidentified white amorphous powder. The reduction of IIa by lithium aluminum hydride in THF at room temperature gave mercury metal and IIIa in yields of 86% and 93%, respectively.

In the same manner, phenyl isocyanide (Ib) reacted with mercuric acetate in THF solution at room temperature to afford the corresponding organomercuric compound (IIb) in 11.5% yield, mercury metal and an oxidized product. Oxidation of Ib by mercuric acetate took place in dry THF solution. The reaction of the oxidized product with water and with ethylamine gave diphenylurea and phenylethylurea, respectively. These results suggest that the oxidized product is phenyl isocyanide diacetate. Compound IIb is sensitive to water and hydrolyzed completely to acetanilide and a white amorphous powder in aqueous THF at room temperature.

The reaction of t-butyl isocyanide with mercuric acetate gave *N*-t-butyl acetamide (23%), t-butyl acetate (12%), mercurous acetate and mercuric cyanide. t-Butyl acetate and mercuric cyanide probably were formed by a transalkylation reaction as follows.

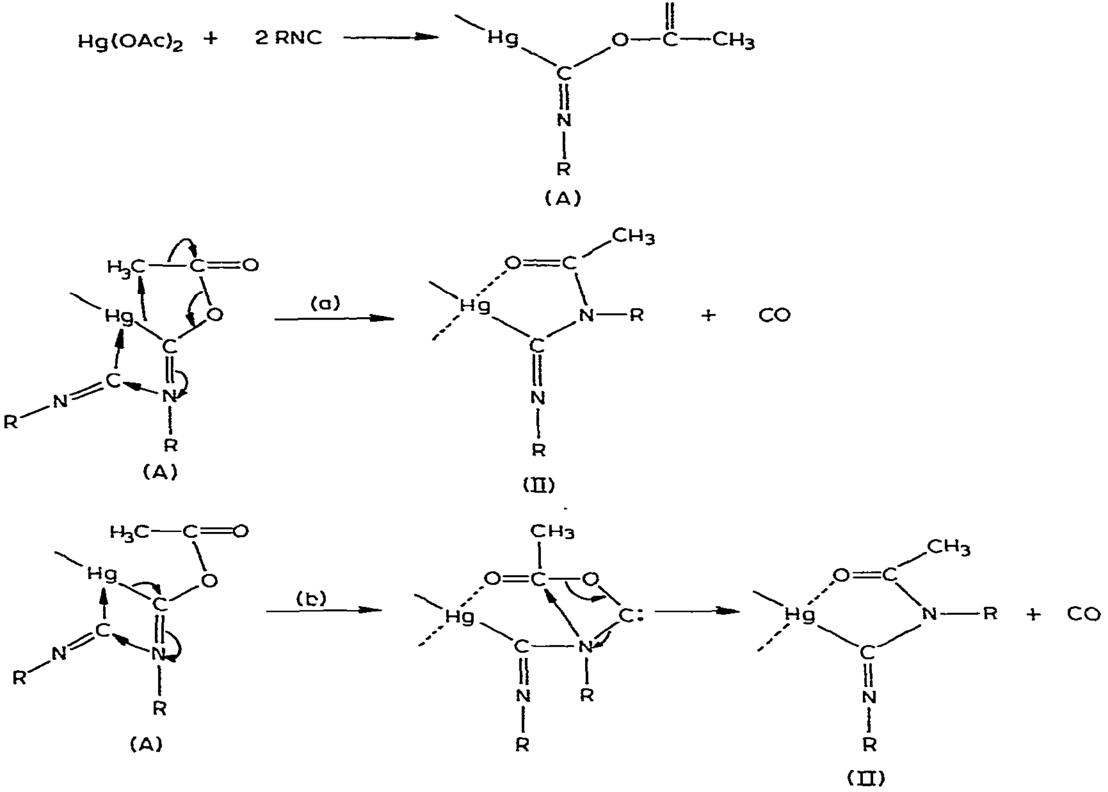
$$\mathrm{Hg(OAc)_2 + 2\ t\text{-}BuNC \rightarrow Hg(CN)_2 + 2CH_3COO\text{-}t\text{-}Bu}$$

A similar transalkylation reaction was observed in the reaction of t-butyl isocyanide with mercuric chloride [4]. *N*-t-Butyl acetamide could be formed by hydrolysis of the intermediate organomercuric compound (IIc). Similarly, cyclohexyl isocyanide reacted with mercuric acetate in THF at reflux to afford *N*-cyclohexyl acetamide. The corresponding organomercuric compound may be formed from an alkyl isocyanide and mercuric acetate. It presumably is too unstable to permit isolation and is hydrolyzed to the acetamide derivative. Attempts to isolate the organomercuric compound from alkyl isocyanides and mercuric acetate in dry THF were unsuccessful.

Reaction scheme

The mechanism of the formation of the new organomercuric compound II from reaction of the isocyanide with mercuric acetate is unclear. However, we can tentatively propose a reaction sequence as shown in Scheme 2.

SCHEME 2



The isocyanide could react with mercuric acetate to give an intermediate acetoxymercuration adduct (A). The intermediate A was postulated to be involved in the preparation of ureas and urethanes from isocyanides, mercuric acetate and nucleophiles [1]. Further, the isocyanide reacts with A to give II with the evolution of carbon monoxide. Two modes of carbon monoxide evolution are considered. In one case a, carbon monoxide originates from acetate . In the another case b, carbon monoxide originates from a carbon atom of the isocyanide.

TABLE 1

CRYSTAL DATA OF IIa

Chemical formula	$C_{38}H_{42}O_2N_4Hg$
Crystal system	Monoclinic
Space group	$C2/c$
Cell dimensions	
a	23.285(7) Å
b	7.991(3) Å
c	19.709(6) Å
β	101.23(2) Å
V	3597.1(36) $Å^3$
Z	4
μ for Cu-K_α	87.9 cm^{-1}
D	1.45 g cm^{-3}

The crystal structure determination of IIa by X-ray diffraction

The molecular and crystal structures of the compound IIa was determined by X-ray diffraction. Suitable crystals for X-ray analysis were obtained by recrystallization from THF/ether. The unit cell dimensions were determined from angular setting values of 14 *hkl* reflections measured on a Philips four-circle X-ray diffractometer with Cu-K_α radiation and refined by the least-squares method. The crystal data are listed in Table 1. From the absence of reflections, *hkl* when $h + k = 2n + 1$, and $h0l$ when $l = 2n + 1$, the space group was determined as either $C_{2/c}$ or C_c. The former was chosen by assuming that the complex molecule has a two fold rotation axis which coincides with a crystallographic diad axis. This was confirmed by the present structure determination. The intensities of 3368 reflections up to $2\theta = 156°$ were measured by the diffractometer with graphite monochromated Cu-K_α radiation ($\lambda = 1.51418$ Å). The $\theta - 2\theta$ scan technique was employed. The size of the crystal was about 0.1 × 0.18 × 0.2 mm which gives the approximate μR value of 0.7. The intensity data were corrected for Lorentz and polarization factors but not for absorption. All the calculations were carried out on a HITAC 8800/8700 computer at the University of Tokyo. The coordinates of the Hg atom were deduced from a three-dimensional Patterson map. The positions of other non-hydrogen atoms were determined from three-dimensional Fourier synthesis phased by the contributions of the Hg atom. The block-diagonal least-squares refinement was carried out. Several cycles of refinement with anisotropic thermal parameters reduced the R value to 0.038 for 3368 reflections. The atomic scattering factors used were taken from the International Tables for X-ray Crystallography [5].

Table 2 lists the final positional and thermal parameters *.
The molecular structure is shown in Fig. 1. The bond lengths and angles are shown in Fig. 2. The average estimated standard deviations in the bond lengths and angles are about 0.013 Å and 0.81°, respectively. The molecule has a C_2

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[*] The table of structure factors has been deposited as NAPS Document No. 02829 (10 pages). Order from ASIS/NAPS, c/O Microfiche Publications, P.O. Box 3513, Grand Central Station, New York, N.Y. 10017. A copy may be secured by citing the document number, remitting $ 5.00 for photocopies or $ 3.00 for microfiche. Advance payment is required. Make checks payable to Microfiche Publications. Outside of the United States and Canada, postage is $ 3.00 for a photocopy or $ 1.50 for a fiche.

TABLE 2

THE FINAL POSITIONAL AND THERMAL PARAMETERS OF IIa

	x	y	l	B_{11}	B_{22}	B_{33}	B_{12}	B_{13}	B_{23}
Hg	0(0)	7656(3)	25000(0)	86(0)	1426(4)	283(1)	0(0)	39(0)	0(0)
O(1)	442(2)	2761(6)	3530(2)	18(1)	266(9)	47(1)	9(2)	5(1)	—32(3)
N(1)	1200(2)	—352(6)	2361(2)	11(1)	192(8)	33(1)	3(2)	5(1)	—2(3)
N(2)	1238(2)	1390(6)	3295(2)	12(1)	196(8)	26(1)	—1(2)	3(1)	4(2)
C(1)	921(2)	553(6)	2711(3)	9(1)	176(9)	29(1)	2(2)	3(1)	14(3)
C(2)	876(2)	—1194(7)	1774(3)	12(1)	193(10)	38(2)	5(2)	8(1)	—8(3)
C(3)	669(2)	—2821(8)	1836(4)	17(1)	183(10)	53(2)	1(3)	10(1)	—1(4)
C(4)	371(3)	—3627(10)	1216(5)	22(1)	218(13)	74(4)	—10(4)	9(2)	—41(6)
C(5)	291(3)	—2812(11)	574(4)	28(2)	335(19)	51(3)	—7(5)	5(2)	—35(6)
C(6)	513(3)	—1294(11)	535(4)	30(2)	290(15)	40(2)	—3(4)	5(2)	—31(5)
C(7)	796(3)	—401(8)	1124(3)	21(1)	234(12)	33(2)	—2(3)	6(1)	—8(4)
C(8)	777(4)	—3660(11)	2526(5)	32(2)	255(15)	64(3)	8(5)	10(2)	46(6)
C(9)	1029(4)	1363(10)	1056(4)	39(2)	248(14)	43(2)	—17(5)	12(2)	11(5)
C(10)	965(2)	2464(8)	3672(3)	17(1)	213(11)	32(2)	—3(3)	5(1)	—3(3)
C(11)	1851(2)	993(7)	3516(3)	13(1)	227(11)	27(1)	—1(2)	2(1)	0(3)
C(12)	2270(2)	1950(8)	3275(3)	16(1)	256(13)	36(2)	—15(3)	6(1)	—19(4)
C(13)	2864(3)	1546(11)	3518(4)	15(1)	363(18)	49(2)	—12(4)	5(1)	—49(6)
C(14)	3017(3)	203(14)	3970(4)	16(1)	482(23)	45(2)	19(5)	—4(1)	—41(6)
C(15)	2604(4)	—711(12)	4183(4)	29(2)	467(27)	38(2)	39(5)	—7(2)	9(6)
C(16)	1996(3)	—340(10)	3965(3)	23(1)	334(17)	31(2)	18(4)	0(1)	28(4)
C(17)	2102(3)	3363(11)	2765(4)	29(2)	280(16)	58(3)	—23(4)	13(2)	31(6)
C(18)	1524(4)	—1374(15)	4215(5)	37(2)	468(25)	54(3)	2(6)	10(2)	96(8)
C(19)	1344(3)	3308(12)	4304(4)	25(1)	377(20)	41(2)	—14(5)	4(1)	—43(6)

Estimated standard deviations are in parentheses The values for Hg have been multiplied by 10^5. All values except for Hg have been multiplied by 10^4 The anisotropic thermal parameters are of the form: $\exp[-(B_{11}h^2 + B_{22}k^2 + B_{33}l^2 + 2B_{12}hk + 2B_{13}hl + 2B_{23}kl)]$

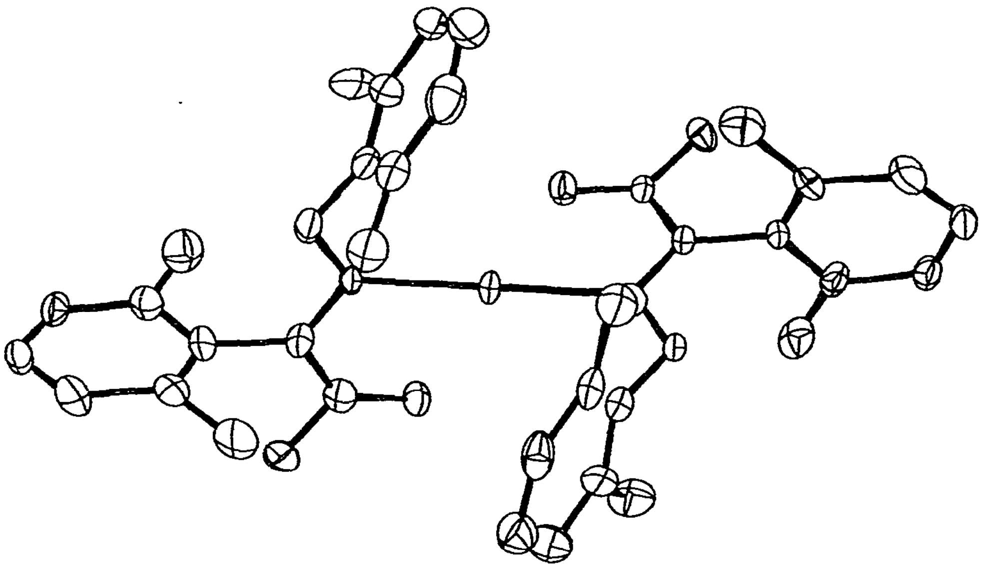

Fig. 1. Molecular structure of IIa.

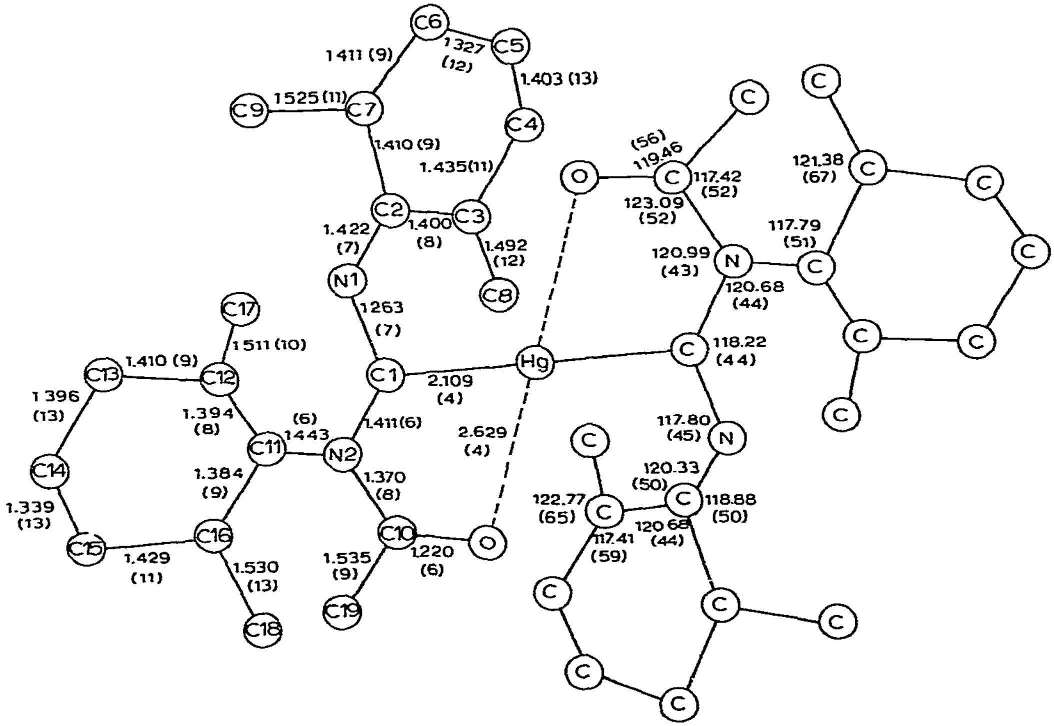

Fig. 2. Bond lengths and bond angles. Dtandard deviations are in parentheses.

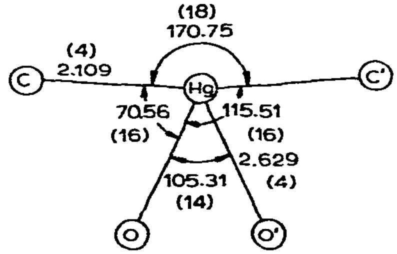

Fig. 3. Schematic drawing of the coordination about the mercury atom. Standard deviations are in parentheses.

symmetry around the central Hg atom. The Hg—C bond distance is 2.109 Å, which accords with the covalent Hg—C bond distance in a common organomercuric compound [6]. The Hg—O bond distance is 2.629 Å, which suggests a weak interaction between the Hg and O atoms. The Hg—O bond distance of oxygen ligand—mercury(II) complexes is 2.1—3.0 Å [7,8]. Mercury has an effective van der Waals radius of 1.73 Å [6] and that of oxygen is 1.40 Å. It is probable that the observed length corresponds to the coordination of carbonyl oxygen to the mercury. The geometry around the mercury is an extremely distorted tetrahedral configuration as shown in Fig. 3. The C—Hg—C bond angle is not linear but is a little bent. The atoms O, N(1), N(2), C(1), C(2), C(10) and C(19) lie approximately on a plane, the deviation from the least squares plane formed by the 7 atoms being within 0.03 Å. The C(11) and Hg atoms are out of this plane by 0.12 and 0.26 Å, respectively. The angle between a set of the two planes around the Hg atom which are related by the diad axis is 89° 22′.

Experimental

All the melting points were uncorrected. The IR spectra were recorded with a JASCO DS-402 spectrometer. The NMR spectra were taken with a JEOL TMN-TS-100 spectrometer. The mass spectra were measured with a JEOL SG-01 apparatus. The gas chromatographic analyses were carried out with a Yanagimoto G-800 gas chromatograph on a 2 m column packed with Carbowax 1500 on Diasolid M at 60° C, Carbowax 20M on Diasolid M at 160° C, silica gel at 90° C and active carbon at 90° C. Isocyanides were prepared by the method of Ugi and coworkers [9].

Reaction of Ia with mercuric acetate

A mixture of mercuric acetate (3.18 g, 10 mmol) and Ia (5.23 g, 40 mmol) in dry THF (50 ml) was refluxed for 5 h with stirring under nitrogen. After cooling, a grayish white precipitate (1.30 g) was removed by filtration. The filtrate was concentrated to a few ml in vacuo and treated with 30 ml of dry ether to separate white crystals. The separated materials were collected and recrystallized from THF/ether to give purified IIa (2.057 g, 26.1%), m.p. 224—225° C. Found: C, 58.14; H, 5.57; N, 7.13. $C_{38}H_{42}O_2N_4Hg$ calcd.: C, 58.01; H, 5.34; N, 7.12%. IR in KBr tablet (cm^{-1}): 1660, 1648, 1603, 1578, 1470. NMR in $CDCl_3$ (δ, ppm): 1.80 (s, 3H), 1.82 (s, 6H), 2.16 (s, 6H), 6.81 (s, 3H), 7.07 (s, 3H). Mass spectrum found (acceleration voltage, 8KV): $M^+ \approx$ 790 (calcd.: 787).

Gas chromatographic analysis of the reaction mixture

A mixture of mercuric acetate (0.635 g, 2 mmol) and Ia (1.048 g, 8 mmol) in THF solution was heated at reflux for 5 h under helium with stirring. After cooling, the reaction mixture and the gas phase were subjected to GLC. The formation of carbon monoxide and carbon doixide was confirmed by using two columns packed with silica gel and activated carbon at 100°C. The identification of carbon monoxide and carbon dioxide was carried out by comparison of the retention times of GLC with those of authentic samples. No formic acid was detected in the reaction mixture by using a Carbowax 20M column.

Hydrolysis of IIa

The solution of IIa (300 mg) in 10 ml of THF containing 1 ml of water was refluxed for 5 h. The solution was dried over anhydrous magnesium sulfate, concentrated under reduced pressure and chromatographed on silica gel. White crystals and a white amorphous powder were obtained by using benzene/methylene chloride and acetone as eluents, respectively. Recrystallization of the white crystals from chloroform/n-hexane gave IIIa (117.5 mg, 94.5%), m.p. 182—184°C. The identification of IIIa was carried out by a mixture mp with an authentic sample prepared from acetic anhydride and 2,6-xylidine.

Reduction of IIa with lithium aluminum hydride

Lithium aluminum hydride (200 mg) was added to a solution of IIa (300 mg) in dry THF (10 ml). The reaction mixture was stirred for 5 h at room temperature. Metallic mercury (65 mg, 86%) precipitated. Aqueous ether (20 ml) was added to the reaction mixture. The solution was dried over anhydrous magnesium sulfate, filtered and washed with ether. The filtrate was concentrated in vacuo and chromatographed on silica gel to give white crystals by using benzene/methylene chloride as an eluent. Recrystallization from chloroform/n-hexane gave IIIa (116.5 mg, 93%).

Reaction of Ib with mercuric acetate

A mixture of mercuric acetate (1.27 g, 4 mmol) and Ib (2.1 g, 20 mmol) in THF (20 ml) was stirred for 5 h at room temperature under nitrogen. A mixture of metallic mercury and mercurous acetate (695 mg) was removed by filtration. The filtrate was concentrated and treated with dry ether and n-hexane to separate a yellowish white residue. Recrystallization from chloroform/n-hexane gave crystalline IIb (310 mg, 11.5%), m.p. 195—198°C. Found: C, 53.49; H, 4.03; N, 8.52. $C_{30}H_{26}O_2N_4Hg$ calcd.: C, 53.43; H, 3.86; N, 8.31%. IR in KBr tablet (cm^{-1}): 1645, 1609, 1590, 1493. NMR in $CDCl_3$ (δ ppm): 1.97 (s, 3H), 6.8—7.5 (broad m, 10H).

The filtrate was treated with ethylamine to yield white crystals. Recrystallization from ether/chloroform gave phenylethylurea which was identified by mixture m.p. with that of authentic sample (293 mg, 33%), m.p. 95—96°C.

Concentration of the filtrate and chromatography on silica gel gave white crystals. Recrystallization from chloroform gave purified *N,N'*-diphenylurea (257 mg, 56%), m.p. 246—247°C.

Hydrolysis of IIb

Compound IIb (300 mg) was dissolved in aqueous THF solution and refluxed for 2 h. The reaction mixture was concentrated to a few ml and chromatographed on silica gel to give white crystals by using benzene as an eluent. Recrystallization from methylene chloride/n-hexane gave crystalline acetanilide (112 mg, 93%), m.p. 110—112°C.

Reaction of t-butyl isocyanide with mercuric acetate

A mixture of t-butyl isocyanide (1.5 g, 20 mmol) and mercuric acetate (1.594 g, 5 mmol) in dry THF (20 ml) was heated at reflux for 5 h with stirring under nitrogen. The reaction mixture was subjected to GLC analysis with a Carbowax 1500 column and a dioctyl sebacate column at 60°C. The formation of t-butyl acetate (12%) was confirmed by comparison of the GLC retention time with that of authentic sample prepared from t-butanol and acetic anhydride. The precipitated grayish mercurous acetate (0.712 g) was removed by filtration from the reaction mixture. The filtrate was concentrated under reduced pressure and treated with 40 ml of n-hexane to separate yellow and white powders. The IR spectrum of the white powders shows a sharp absorption at 2195 cm^{-1} due to $\nu(\mathrm{C{\equiv}N})$. Cyanide ion was also confirmed to exist in the white powders by qualitive analysis using cupric acetate and benzidine acetate [10]. Treatment of the white powders with hydrogen sulfide gave a black precipitate of mercuric sulfide in acidic aqueous solution. These results indicated that the white powders contained mercuric cyanide. Evaporation of the filtrate gave a white residue whose sublimation gave white needles *N*-t-butyl acetamide (266 mg, 23%), m.p. 95—96°C. *N*-t-butyl acetamide was identified by a mixture m.p. with an authentic sample prepared from acetic anhydride and t-butylamine.

Reaction of cyclohexyl isocyanide with mercuric acetate

A solution of cyclohexyl isocyanide (2.18 g, 20 mmol) and mercuric acetate (1.59 g, 5 mmol) in dry THF (20 ml) was heated at reflux for 5 h under nitrogen. A grayish white precipitate of mercurous acetate were removed by filtration. The reaction mixture was concentrated under reduced pressure and treated with 20 ml of ether to separate a brown powder. The solution was concentrated and subjected to chromatography on silica gel. White crystals were obtained by using methylene chloride as an eluent. Recrystallization from methylene chloride/n-hexane gave *N*-cyclohexylacetamide (169 mg, 12%), m.p. 240—241°C. It was identified by comparison of its IR spectum and m.p. with those of an authentic sample.

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