BENZOYL AND TRICHLOROACETYL ISOCYANATES IN CYCLO-FORMATION REACTIONS

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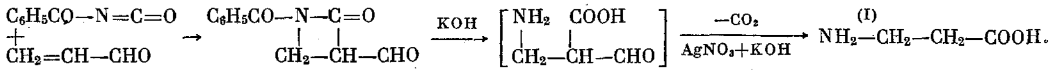
UDC 542.91+547.239.1

In previous communications we had shown that the benzoyl and trichloroacetyl isocyanates react with compounds, containing double or triple carbon–carbon bonds, either by the 1,2-cyclo-addition type, with the formation of 4-membered rings, or by the 1,4-cyclo-addition type, with the formation of 6-membered rings, depending on the nature of the olefin or acetylenic compound and on the nature of the isocyanate [1-3].

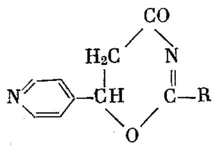
As a continuation of this research we studied the reaction of benzoyl isocyanate and trichloroacetyl isocyanate with acrolein, γ-vinylpyridine, p-halo-substituted phenylacetylenes, and diphenylacetylene. Benzoyl isocyanate reacts readily with acrolein to give a crystalline adduct (I) with a 4-membered ring, having mp 210°

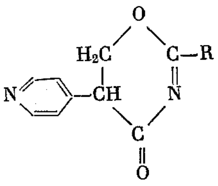

(I)

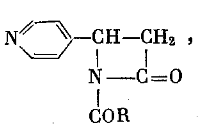
$$C_6H_5CO{-}N{=}C{=}O + CH_2{=}CH{-}CHO \rightarrow \begin{matrix} C_6H_5CO{-}N{-}C{=}O \\ | \quad\ | \\ CH_2{-}CH{-}CHO \end{matrix} \xrightarrow{KOH} \left[\begin{matrix} NH_2 \quad COOH \\ | \qquad | \\ CH_2{-}CH{-}CHO \end{matrix}\right] \xrightarrow[AgNO_3+KOH]{-CO_2} NH_2{-}CH_2{-}CH_2{-}COOH.$$

The structure of (I) was established chemically and by the IR spectra. In the IR spectrum (Nujol) are present the frequency $\nu_{C=O}$ 1780 cm^{-1} of the β-lactam ring, $\nu_{C=O}$ 1718 cm^{-1} of the aldehyde group, and $\nu_{C=O}$ 1690 cm^{-1} of the benzoyl radical. The alkaline hydrolysis of (I), followed by oxidation of the hydrolysis product with moist silver oxide, gave β-alanine hydrochloride with mp 122.5° (from [4]: mp 123°).

The reaction of trichloroacetyl isocyanate with acrolein goes differently. A hard glassy polymer is obtained, which does not melt up to 300°, and has a mol. wt. of 564 (dioxane). In the IR spectrum of the polymer are present the absorption frequency $\nu_{C=O}$ 1810 cm^{-1} of a 4-membered ring, and $\nu_{C=O}$ 1731 and 1700 cm^{-1} of the triacetyl radical. The reaction of the benzoyl and trichloroacetyl isocyanates with γ-vinylpyridine goes easily, with the formation of crystalline yellow products, with mp 93-94° (decomp.) for trichloroacetyl isocyanate, and 113-114° (decomp.) for benzoyl isocyanate. Taking into account the fact that γ-vinylpyridine reacts easily as a dienophile, the reaction products can be assigned the following structural formulas (with either a 6-membered or a 4-membered ring)


(IIa)


(IIb)


(IIc)

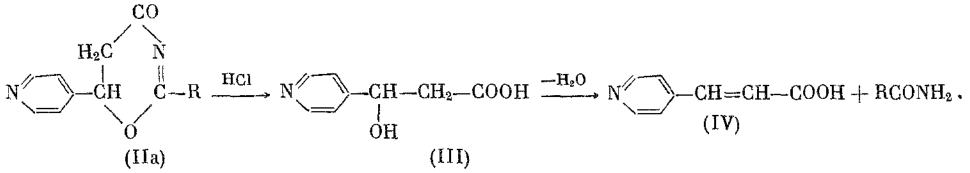
where R = CCl_3, C_6H_5.

The IR spectra of both reaction products are devoid of the frequencies of a carbonyl group in a 4-membered ring. The product, in which R = CCl_3, has in the IR spectrum (Nujol) $\nu_{C=O}$ 1700 and $\nu_{C=N}$ 1655 cm^{-1}; the product, in which R = C_6H_5, has in the IR spectrum (Nujol) $\nu_{C=N}$ 1680 and $\nu_{C=N}$ 1640 cm^{-1}. The low absorption frequencies of the C = O group make it possible to exclude structure (IIc).

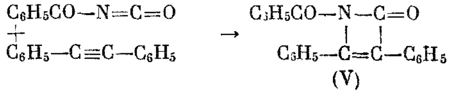
V. I. Ul'yanov-Lenin Kazan State University. Translated from Izvestiya Akademii Nauk SSSR, Seriya Khimicheskaya, No. 3, pp. 577-581, March, 1971. Original article submitted June 26, 1969.

The UV spectra of the obtained products corroborate the presence of conjugated systems in them, and they have the absorption bands λ_{max} 250 nm (log ε 4.1) and λ_{max} 410 nm (log ε 1.97).

The choice between formulas (IIa) and (IIb) was made in favor of (IIa) on the basis of studying the hydrolysis products. The acid hydrolysis of the adduct of γ-vinylpyridine and trichloroacetyl isocyanate gave acid (III), which when heated with $KHSO_4$ easily cleaves water to give 2-(4-pyridyl)acrylic acid (IV) with mp 294-295° (from [5]: mp 294-295°). On this basis we believe that acid (III), with mp 168-169.5°, is 2-(4-pyridyl)-2-hydroxypropionic acid

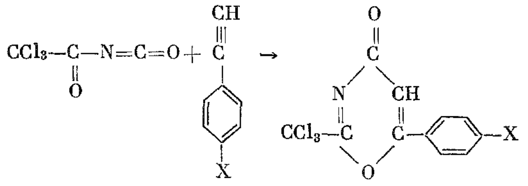


The structure of the adduct of benzoyl isocyanate and γ-vinylpyridine was established in a similar manner. The reaction of benzoyl isocyanate with diphenylacetylene proceeds with greater difficulty, with the formation of a crystalline product with mp 214°, which, on the basis of the data of the IR spectrum (Nujol) ($\nu_{C=O}$ 1760 cm^{-1} of the β-lactam ring, $\nu_{C=O}$ 1680 cm^{-1} of the benzoyl radical) must be assigned the structure of (V), containing a 4-membered ring



In contrast to diphenylacetylene, the reaction between the p-halo-substituted phenylacetylenes and trichloroacetyl isocyanate proceeds easily at room temperature with the formation of crystalline substances. For X = Cl (VI), mp 181-182°, for X = Br (VII), mp 187-188°, and for X = F (VIII), mp 155-156°.

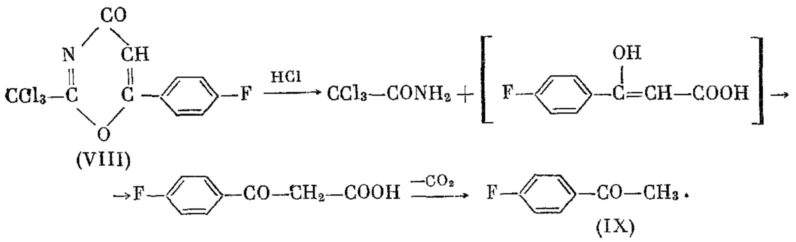
The data of the IR spectra (Nujol) indicate the absence of a 4-membered ring and the formation of a conjugated system due to 1,4-cyclo-addition to the triple bond


(VI) – (VIII)

Thus, for (VI) $\nu_{C=O}$ 1700, $\nu_{C=C}$ 1610, $\nu_{C=N}$ 1667 cm^{-1}; for (VII) $\nu_{C=O}$ 1703, $\nu_{C=C}$ 1610, $\nu_{C=N}$ 1655 cm^{-1}; for (VIII) $\nu_{C=O}$ 1700, $\nu_{C=C}$ 1610, $\nu_{C=N}$ 1660 cm^{-1}.

The UV spectra of (VI) and (VIII) also indicate the presence of a strongly conjugated system of double bonds, and they have the absorption bands λ_{max} 275 mμ (log ε = 6.51), λ_{max} 286 mμ (log ε = 6.32) and λ 333 mμ (log ε = 5.72), λ 338 mμ (log ε 5.68).

The data of the IR and UV spectra were corroborated by the chemical transformations. Since the spectra of (VI)-(VIII) are analogous, only (VIII) was investigated chemically. The acid hydrolysis of (VIII) gave p-fluoroacetophenone, which was identified by gas-liquid chromatography



In contrast to trichloroacetyl isocyanate, benzoyl isocyanate does not react with p-halo-substituted phenylacetylenes, and instead the formation of the benzoyl isocyanate dimer with mp 157-158° occurs. The IR spectrum of the dimer has an absorption band in the 1815 cm^{-1} region, caused by the stretching vibrations of the C = O group of the oxazetidinone ring, while absorption bands are present at 1726, 1712, and 1635 cm^{-1} in the region for the manifestation of the stretching vibrations of the C = O and C = N bonds. The mixed melting point of the given dimer with the dimer, obtained previously [3], was not depressed.

EXPERIMENTAL METHOD

Reaction of Benzoyl Isocyanate with Acrolein (I). Benzoyl isocyanate (4 g) and 1.6 g of acrolein was mixed in a dry atmosphere. White crystals deposited within several minutes, which were filtered and washed with absolute ether. The melting point of the pure crystals was 210°; yield 3.1 (51.1% of theory). Found: C 64.89; H 4.53%. $C_{11}H_9NO_3$. Calculated: C 65.02; H 4.43%.

Reaction of Trichloroacetyl Isocyanate with Acrolein. Trichloroacetyl isocyanate (3 g) and 0.96 g of acrolein were mixed in a flask fitted with a ground-glass stopper. The reaction mixture gradually thickened and after standing for a week was converted to a hard glassy yellow mass. The obtained product was dissolved in hot THF and then precipitated with petroleum ether. The product does not melt even when heated up to 300°; mol. wt. 564 (cryoscopically in absolute dioxane).

Reaction of Trichloroacetyl Isocyanate with γ-Vinylpyridine. With vigorous stirring, 5.95 g of trichloroacetyl isocyanate was added in drops to a solution of 3.3 g of γ-vinylpyridine in 100 ml of absolute ether at room temperature. The reaction was ended in 30 min. The obtained yellow crystals were washed in succession with absolute ether, benzene and hot acetone. We obtained 8.26 g (67%) of compound (IIa) with mp 93-94° (decomp.). Found: C 41.08; H 2.21; Cl 35.98; N 9.15%. $C_{10}H_7N_2O_2Cl_3$. Calculated: C 40.88; H 2.38; Cl 36.18; N 9.54%.

Reaction of Benzoyl Isocyanate with γ-Vinylpyridine. With vigorous stirring, 3.07 g of benzoyl isocyanate was added in drops to a solution of 2.19 g of γ-vinylpyridine in 100 ml of absolute ether at room temperature. The reaction was ended in 30 min. A yellow precipitate deposited, which was repeatedly washed with ether, benzene, and CCl_4. We obtained 4.26 g (81%) of compound (IIIa) with mp 113-114° (decomp.). Found: C 71.21; H 4.58; N 10.69%. $C_{15}H_{12}N_2O_2$. Calculated: C 71.42; H 4.76; N 11.11%.

Reaction of Trichloroacetyl Isocyanate with p-Fluorophenylacetylene. Trichloroacetyl isocyanate (3.8 g) was mixed in a tube with 2.62 g of p-fluorophenylacetylene, obtained as described in [6], in a dry CO_2 atmosphere. The reaction was run without a solvent at room temperature. After 2 h the obtained crystals were filtered and repeatedly washed with absolute ether. We obtained 2.09 g (31.4%) of (VIII) with mp 155-156°. Found: C 42.98; H 1.68%. $C_{11}H_5NO_2Cl_3F$. Calculated: C 42.78; H 1.62%.

Reaction of Trichloroacetyl Isocyanate with p-Chlorophenylacetylene. Trichloroacetyl isocyanate (2.35 g) was mixed in a tube with 1.7 g of p-chlorophenylacetylene, obtained as described in [6], in a dry CO_2 atmosphere. The reaction mixture was kept in the sealed tube for 12 h at room temperature. The obtained crystals were filtered and washed with absolute ether. We obtained 0.93 g (20.29%) of (VI) with mp 181-182°. Found: C 40.78; H 1.63; Cl 42.88%. $C_{11}H_5NO_2Cl_4$. Calculated: C 40.61; H 1.51; Cl 42.55%.

Reaction of Trichloroacetyl Isocyanate with p-Bromophenylacetylene. Trichloroacetyl isocyanate (5 g) and 5.2 g of p-bromophenylacetylene, obtained as described in [6], were mixed in a tube, filled with dry CO_2, without a solvent. The reaction mixture was heated at 50° for 5 h. The obtained crystals were filtered and repeatedly washed with absolute ether. We obtained 3.76 g (37%) of (VII) with mp 187-188°. Found: C 35.76; H 1.34%. $C_{11}H_5NO_2Cl_3Br$. Calculated: C 35.76; H 1.36%.

Reaction of Benzoyl Isocyanate with Diphenylacetylene (V). A mixture of 2.35 g of benzoyl isocyanate and 2.85 g of diphenylacetylene was heated at 60° for a month. The obtained crystals were filtered and recrystallized from petroleum ether. We obtained 0.020 g (0.4%) of (V) with mp 214°. Found: C 81.19; H 4.58%. $C_{22}H_{15}NO_2$. Calculated: C 81.21; H 4.61%.

Hydrolysis of Compound (I). A solution of 0.28 g of (I) in 7 ml of 5 N alcoholic KOH solution was heated at 80° for 1 h. Then a solution of 0.465 g of $AgNO_3$ in 7 ml of distilled water was added to the solution, and the reaction mixture was refluxed for another 30 min. The obtained precipitate was filtered. Acidification of the filtrate gave white crystals of the salt $HCl \cdot NH_2CH_2CH_2COOH$ with mp 122.5°.

Hydrolysis of Compound (VIII). We heated (VIII) (0.4 g) in 5 ml of distilled water, acidified with conc. HCl to pH 4-3.5, at 80-90° for 5 h. Separation of the liquid into two layers and the deposition of crystals occurred when the reaction mixture was cooled. The crystals were filtered and recrystallized from diethyl ether. The pure crystals had mp 139-140° and were trichloroacetamide. The liquid separated into two layers. The lower layer was an oily liquid with the characteristic odor of p-fluoroacetophenone, and was investigated on a GL chromatograph of the UKh-1 type at 155° and a pressure of 1.8/0.8 atm. The substance had the same exit time and character of the peak as a standard specimen of p-fluoroacetophenone.

Hydrolysis of Compound (IIa). To a solution of 0.9 g of (IIa) in 2 ml of acetone were added 1 ml of water and two drops of 2 N HCl solution. The solution was heated at 40° for 45 min. After standing at room temperature for 30 min the reaction mixture was diluted with an equal volume of water and allowed to stand for another 30 min. The obtained crystals, with mp 168-168.5°, were dissolved in benzene and the solution was heated with 0.02 g of $KHSO_4$ at 60-70° for 2 h. At the end of heating the $KHSO_4$ was filtered, and the solution was heated with active carbon for 10 min, after which the filtrate was evaporated. After evaporation, crystals of 2-(4-pyridyl)acrylic acid with mp 294-295° were obtained.

CONCLUSIONS

1. Benzoyl isocyanate reacts with acrolein and diphenylacetylene by the 1,2-cyclo-addition type.

2. Benzoyl isocyanate and trichloroacetyl isocyanate react with γ-vinylpyridine by the 1,4-cyclo-addition type, with the formation of six-membered adducts.

3. Trichloroacetyl isocyanate reacts with p-halo-substituted phenylacetylenes by the 1,4-cyclo-addition type.

LITERATURE CITED

1. B. A. Arbuzov and N. N. Zobova, Dokl. AN SSSR, 172, 845 (1967).
2. B. A. Arbuzov, N. N. Zobova, and R. N. Babasina, Izv. AN SSSR, Ser. Khim., 2137 (1968).
3. B. A. Arbuzov, N. N. Zobova, and F. B. Balabanova, Izv. AN SSSR, Ser. Khim., 1570 (1970).
4. F. H. Holm, J. Chem. Soc., 88, 29 (1905).
5. P. Rabe and K. Kindler, Chem. Ber., 52, 1848 (1919).
6. C. Dufraisse and A. Dequesnes, Bull. Soc. Chim. France, [4], 49, 1880 (1931).