duced pressure. A cold solution of the residue in 200 cc. of dry benzene was stirred while ammonia was bubbled in until reaction appeared to be complete. The reaction mixture was filtered, and the filter cake was triturated with water and again isolated by filtration. The dried solid obtained was dissolved in 500 cc. of benzene, and the benzene solution was filtered. The filtrate was concentrated until crystals appeared. Cooling gave 11.7 g. (65%) of amide, m. p. 103–105°. Three recrystallizations from benzene gave a sample with no higher melting point.

Anal. Calcd. for $C_{16}H_{17}NO$: N, 5.85. Found: N, 5.25.

1-Benzoyl-3-phenylurea.—(a) With Solvent: A solution of 12.1 g. (0.1 mole) of benzamide and 11.9 g. (0.1 mole) of phenyl isocyanate in 200 cc. of dry toluene was refluxed for twenty-four hours. The cooled reaction mixture deposited a crystalline product which was removed by filtration and dried. The crude product weighed 24.0 g. and melted at 193–198°. Recrystallization from 135 cc. of dioxane gave 21.5 g. (89%) of 1-benzoyl-3-phenylurea, m. p. 203–204° (lit. 204°). (b) Without Solvent:—A mixture of 12.1 g. (0.1 mole) of benzamide and 11.9 g. (0.1 mole) of phenyl isocyanate was heated slowly to about 115°. At this temperature a vigorous reaction began, and the temperature mounted rapidly to 185°. External heating was stopped when the reaction began to occur vigorously. The mixture became almost completely liquid while the temperature was climbing rapidly, but at about 185° solidification began. The cooled reaction mixture was crystallized from dioxane to give 19.8 g. (82%) of 1-benzoyl-3-phenylurea, m. p. 203–204°.

1-Benzoyl-3-ethylurea.—A solution of 7.1 g. (0.1 mole) of ethyl isocyanate and 12.1 g. (0.1 mole) of benzamide in 150 cc. of dry toluene was refluxed for eighteen hours. When the reaction mixture was refrigerated, a crystalline precipitate formed. This precipitate proved to be 4.5 g. of benzamide, m. p. 120–124° and no depression in melting point upon admixture with benzamide. Evaporation of the toluene solution under reduced pressure left a white residue. This residue was recrystallized three times from alcohol. The final product was 7.3 g. of white needle-like crystals, m. p. 112–114° (lit. 114–115°); yield 38%.

1-Butyryl-3-ethylurea.—A mixture of 8.7 g. (0.1 mole) of butyramide and 7.1 g. (0.1 mole) of ethyl isocyanate was dissolved in 100 cc. of dry toluene. The solution was refluxed for twenty-four hours, cooled and filtered. The solvent was removed from the filtrate by evaporation under reduced pressure. Two recrystallizations of the residue from alcohol gave 4.0 g. (25%) of 1-butyryl-3-ethylurea, m. p. 98.5–100°, crystallizing in irregular oblong plates.

Anal. Calcd. for $C_7H_{14}N_2O_2$: N, 17.72. Found: N, 17.79.

Phenyl Isothiocyanate and Benzamide.—A mixture of 12.1 g. (0.1 mole) of benzamide and 13.5 g. (0.1 mole) of phenyl isothiocyanate was heated at a temperature of 180–190° for four hours. The reaction mixture was recrystallized four times from alcohol. The only product isolated was 2.9 g. of a light tan solid melting at 149–153°. Several more recrystallizations from alcohol gave a cream colored product melting at 157–159°. The melting point of a mixture with benzanilide (m. p. 160°) was 158–160°.

Anal. Calcd. for $C_{12}H_{11}NO$: C, 77.84; H, 5.95; N, 7.56. Found: C, 78.18; H, 5.74; N, 7.34.

Phenyl Isothiocyanate and Acetamide.—A mixture of 13.5 g. (0.1 mole) of phenyl isothiocyanate and 5.9 g. (0.1 mole) of acetamide was heated at 180–190° for four hours. Cooling gave a dark brown liquid which had no isothiocyanate odor or lachrymatory properties but did smell strongly of hydrogen sulfide. The residue was dissolved in an equal volume of absolute alcohol and cooled. The precipitate which formed was removed and recrystallized from alcohol. There was obtained 2.3 g. of acetanilide melting at 110–112°. The mixed melting point with authentic acetanilide (m. p. 113–115°) was 112–114°.

Summary

1. The reaction of isocyanates with unsubstituted amides to give acylaryl- or alkylureas has been found to be quite general. The effects on the reaction of temperature, solvent, time, catalysts, and different types of amides and isocyanates have been studied.

2. Phenyl isothiocyanate has been found to react with amides only under severe conditions giving anilides.

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[CONTRIBUTION FROM THE DEPARTMENTS OF AGRICULTURAL CHEMISTRY AND OF CHEMISTRY, UNIVERSITY OF MISSOURI]

Hydrogen Bonding in Some 4-Substituted Cyclohexanols

BY E. E. PICKETT AND H. E. UNGNADE

The spectroscopic evidence for hydrogen bonding in liquid alcohols has been studied extensively. In pure liquid alcohols there is a broad intense absorption band peaked between 2.95 and 3.00μ attributed to associated molecules, which decreases in intensity with dilution in an inert solvent, and a sharper band appears at 2.75μ, arising from single molecules.

Fox and Martin[1] resolved the association band of certain alcohols into two components. They suggested that the shorter wave length component is due to dimers and the longer wave length component is due to higher polymers. In the dimer form no single molecule serves as both donor and acceptor of hydrogen and the OH stretching force constant thus differs from that of the higher polymer.

In a study of several of the isomeric hexanols[2] it was found that the formation of polymers higher than dimers was inhibited in all of those isomers which contained the structures —C(R)—C—OH or —C(R)—OH.

With the *cis* and *trans* 4-phenyl and cyclohexylcyclohexanols at hand,[3] the question arose as to whether differences in steric inhibition of hydrogen bonding could be detected spectroscopically in such compounds. On the basis of viscosity and molecular weight determinations, the *cis* alcohols are thought to be less associated than the *trans* alcohols, but the 4-substituents are less effective than the 2-substituents in preventing association.[4]

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[1] Fox and Martin, *Proc. Roy. Soc. (London)*, **A162**, 419 (1937).

[2] Stanford and Gordy, THIS JOURNAL, **62**, 1247 (1940).

[3] Ungnade, *J. Org. Chem.*, **13**, 361 (1948).

[4] Hückel, Kumetat and Preuss, *Ann.*, **517**, 229 (1935); Gough, Hunter and Kenyon, *J. Chem. Soc.*, 2052 (1926).

Experimental

The samples were prepared and purified in an earlier investigation by one of us.[3] Optical properties, melting point diagrams, and other properties have been determined for these compounds and they are believed to be of high purity. Solutions of them were made up to the desired molarities in purified carbon tetrachloride. A single 1.00 mm. absorption cell, refillable without dismantling, was used for all samples. The concentration range employed was imposed by the solubility of the samples or by the cell thickness. Point-by-point per cent. transmission measurements were made against air, at constant slit width, in the range 2.68 to 3.20μ at every 0.02μ interval by means of a Beckman IR-2 spectrophotometer. Recorder tracings indicated that this measurement interval was acceptable. The spectra are presented in Fig. 1. The curve marked CCl_4 shows the transmission of the cell filled with pure carbon tetrachloride.

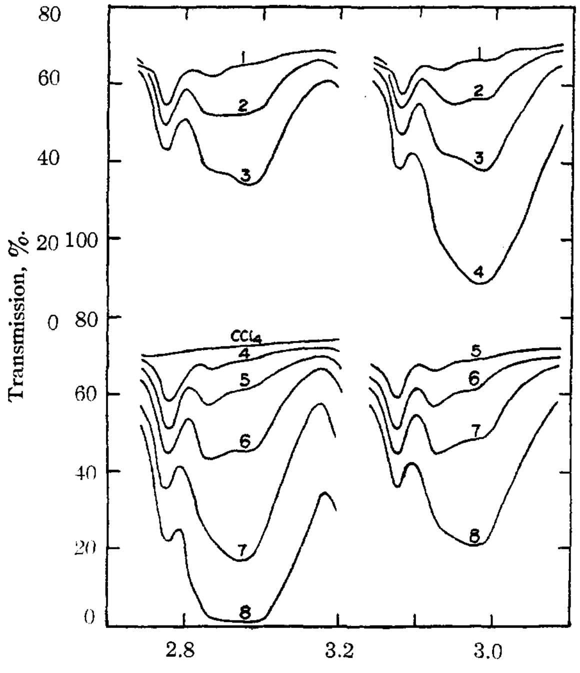

Fig. 1.—Upper left curves: *trans*-4-phenylcyclohexanol in CCl_4 soln.; 1, 0.051 *M;* 2, 0.103 *M;* 3, 0.159 *M.* Lower left curves: *cis*-4-phenylcyclohexanol in CCl_4 soln.; 4, 0.051 *M;* 5, 0.102 *M;* 6, 0.159 *M;* 7, 0.256 *M;* 8, 0.517 *M.* Upper right curves: *trans*-4-cyclohexylcyclohexanol in CCl_4 soln.; 1, 0.050 *M;* 2, 0.100 *M;* 3, 0.154 *M;* 4, 0.247 *M.* Lower right curves: *cis*-4-cyclohexylcyclohexanol in CCl_4 soln.; 5, 0.050 *M;* 6, 0.099 *M;* 7, 0.154 *M;* 8, 0.247 *M.*

Discussion

All of the four compounds exhibit hydrogen bonded absorption regions, 2.8–3.2μ, which increase in intensity with increasing concentration more rapidly than the free OH bands, at 2.75μ. Beer's law "fails" for both types of bands, the deviations being negative for the free OH band and positive for the association band. However, the extinction *versus* concentration curves of both band types are nearly straight above 0.10 molar concentration.

The associated OH absorption regions quite obviously consist of two chief components in each case, centered at about 2.87 and 2.97μ. The former of these may be taken as the dimer component and the latter as the polymer component. At low concentrations the dimer component is more intense than the polymer, the latter being almost absent at the concentration 0.05 molar. The intensity of the polymer component then increases more rapidly than that of the dimer. This behavior seems consistent with the interpretation of these components as being due to dimer and polymer aggregates in solution.

It is apparent that the *trans* forms show somewhat greater hydrogen bonded OH absorption than the corresponding *cis* isomers at similar concentration, as was anticipated, indicating some steric inhibition to intermolecular association in the latter. At a given concentration, the intensity of the dimer component of each *trans* isomer is only slightly greater than that of the corresponding *cis* isomer, while the intensity of the polymer component is considerably greater in the former than in the latter. This suggests that the formation of the polymers is more sensitive to steric interference than is the formation of the dimers.

Moreover, in the spectra of the two *cis* isomers, the intensity of the association band relative to that of the free OH band is somewhat greater for the 4-phenyl than for the 4-cyclohexyl derivative, at each similar concentration, to an extent larger than can be accounted for entirely by the slightly higher molar concentrations of the former, perhaps indicating that the 4-cyclohexyl group is a bit more effective in preventing association than the 4-phenyl group. This effect is of course not observed in the *trans* isomers: the intensities of both the association and the free OH bands are greater for the *trans*-phenyl than for the *trans*-cyclohexyl derivative of similar concentration, and to about the same extent in each band.

Summary

The infrared spectra between 2.7 and 3.2μ of carbon tetrachloride solutions of *cis*- and *trans*-4-phenyl and 4-cyclohexylcyclohexanols were measured in the concentration range 0.05 to 0.5 molar. The *trans* isomers exhibit greater intermolecular association than the *cis* isomers. The 4-cyclohexyl group produces slightly greater interference with association than the 4-phenyl group. Certain other conclusions are obtained from the data.

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