Substitution yields

$$(C_g^0 - \tfrac{1}{2} C_g)\frac{V}{A} = 0.75\,\beta\, C_g[Dk_1]^{1/2}\left(\frac{0.693}{k_{\text{obsd}}}\right)$$

which by rearranging and squaring results in Equation 11.)

$$k_1 = \frac{2.57 \times 10^{-4}}{\beta^2 D}\left[\frac{k_{\text{obsd}} V}{A}\right] \tag{11}$$

where β is the partition coefficient (concentration of iodomethane in liquid per concentration of iodomethane in gas phase), D is the diffusivity of iodomethane in the liquid (square centimeters per second), and the other quantities have already been defined. The partition coefficient of iodomethane between water and air has been determined in this laboratory to be 1.5 at 50° C. for very dilute solutions of iodomethane. The diffusivity of iodomethane was assumed to be 2.5×10^{-5} sq. cm. per second, which is of a correct order-of-magnitude value when compared with the diffusivity of various haloalkanes (*5*).

The liquid reaction rate constant which is calculated from the data in Table II is proportional to the square of the mole fraction of hydrazine hydrate in the solution (Equation 11 and Figure 2) for the concentration range which was studied. The calculated liquid reaction rate for a 5.1-mole per liter solution—i.e., 0.11 mole fraction—is 0.34 second^{-1} which corresponds to a second order rate constant of 0.07 liter mole^{-1} second^{-1}.

The liquid reaction rate constant is estimated to be ca. 0.3 liter mole^{-1} second^{-1} which is a factor of four faster than that calculated by use of Equation 11. (The liquid reaction rate constant has been determined directly in this laboratory to be 0.02 liter mole^{-1} second^{-1} at 21° C. for 0.03 to 0.1*M* hydrazine solutions which are 0.05*M* in sodium hydroxide. With the assumption of an activation energy of 18 kcal. per mole, the reaction rate constant at 50° C. is calculated to be 0.3 liter mole^{-1} second^{-1}.) The experimental dependence of k_1 calculated by Equation 11 on the square of the mole fraction of hydrazine hydrate is quite unexpected and is difficult to rationalize with respect to the second order kinetics which were found for dilute (ca. 0.1*M*) hydrazine solutions. The application of Equation 10 to prediction of rates of iodomethane removal appears to be more reliable than the predicted rate from the diffusion-reaction model.

Treatment of the data in Table III according to the Arrhenius relationship yields an energy of activation of between 5 and 6 kcal. per mole. The energy of activation appears to increase as the temperature is increased. Winning (*11*), in studying the heterogeneous reaction of hydrazine and oxygen, found an energy of activation of 6.4 kcal. per mole which increased as the temperature was increased. Winning suggested that this effect, the increase in energy of activation, was due to the increasing importance of the gas phase reaction. Bowen has reported the energy of activation of the gas phase reaction of hydrazine and oxygen to be 38 kcal. per mole (*2*). This reasoning could be applied to the reaction between hydrazine and iodomethane, and the rate of the gas phase reaction would be predicted to become an increasingly important term as the temperature is increased. (If 5 and 38 kcal. per mole are assumed to be the energy of activation of the first and second terms, and if at 50° C., the contribution of the second term to the over-all rate is 1%, then at 60° and 70° C., the contribution of the second term would be 5 and 24%, respectively.)

ACKNOWLEDGMENT

The author thanks J.A. Partridge and L.L. Burger for their interest and comments.

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RECEIVED for review March 10, 1967. Accepted September 21, 1967. Paper based on work performed under Contract AT(45-1)-1830 between the Atomic Energy Commission and Battelle Memorial Institute. Presented in part to the 22nd Northwest Regional Meeting, ACS, Richland, Wash., June 1967.

Half Amides and Imides of *cis*-Cyclohexane-1,2-dicarboxylic Acid and *cis*-4-Cyclohexene-1,2-dicarboxylic Acid

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THE *cis*-cyclohexane-1,2-dicarboxylic anhydride [m. p. 31° C.; b.p. 161.7-1.9° C. (25 mm.)] and *cis*-4-cyclohexene-1,2-dicarboxylic anhydride (m.p. 103-4° C.) are readily available commercial materials finding use as alkyd, polyester, and epoxy resin intermediates (*2, 3, 16*). The former is prepared by hydrogenating the latter (*13*), which is made by adding maleic anhydride to butadiene (*4, 6*).

Although many miscellaneous half amides and imides have been prepared from these anhydrides, only the *N*-alkyl imide derivatives have been given extensive study (*17, 19,*

The preparation and properties of 19 *cis*-2-(substituted-carbamoyl)cylco-hexanecarboxylic acids, 19 similar *cis*-6-(substituted-carbamoyl)-3-cyclohexene-1-carboxylic acids, and their corresponding 38 imides are described. Pertinent infrared spectral data are also given.

20, 22). The materials are reported to have potential utility as insect repellants (*1, 10, 17, 21*), pyrethrin synergists (7), gasoline antiknock agents (23), and herbicides (*15*). Most notable is the fungicide, Captan, *cis*-*N*-trichloromethylthio-4-cyclohexene-1,2-dicarboximide (*11, 12*).

For comparative purposes, this paper describes the preparation and properties of 38 half amides of *cis*-cyclohexane- and *cis*-4-cyclohexene-1,2-dicarboxylic acids and the 38 corresponding imides. *N*-Alkyl, cycloalkyl, alkenyl, aryl, and heterocyclic derivatives are included. Table I gives the physical and chemical properties of the 19 *cis*-2-(substituted-carbamoyl)cyclohexanecarboxylic acids. Table II provides representative infrared spectral data of these materials. The corresponding information on the other 57 compounds has been deposited in tabular form with the American Documentation Institute. The tables are entitled: "*cis*-2 - (Substituted - carbamoyl) -3- cyclohexene -1- carboxylic Acids," "*cis*-*N*-Substituted 1,2- cyclohexanedicarboximides," "cis-*N*-Substituted -4- cyclohexene -1,2- dicarboximides," and "Infrared Spectral Data (KBr Pellets) on *cis*-2-(Substituted - carbamoyl) -3- cyclohexene -1- carboxylic Acids, *cis*-*N*-Substituted -1,2- cyclohexanedicarboximides, and *cis*-*N*-Substituted -4- cyclohexene -1,2- dicarboximides" (references *5*, *8*, *18*, and *25* are cited in these tables).

EXPERIMENTAL

The half amides were formed by various modifications of the well-known anhydride-amine reaction at 55° to 70° C. All of the imides, except the *p*-nitrophenyl derivatives and one of the 2-chlorophenyl imides (compound 64), were prepared by thermal dehydration of the corresponding half amide. For the three exceptions, dehydration of the half amides to the imides was effected by acetic anhydride and sodium acetate.

The cis configuration for 2-(phenylcarbamoyl)cyclohexanecarboxylic acid and *N*-phenylcyclohexane-1,2-dicarboximide has been definitely established (*1, 2*). On this basis, as well as the published knowledge of the stereochemistry of the Diels-Alder reaction by which the starting *cis*-4-cyclohexane-1,2-dicarboxylic anhydride is obtained, the cis configuration is assigned to all of the half amides and imides in both series.

Infrared spectral data (Table II) on selected samples of the half amides and imides were obtained on a Beckman Model IR-5, sodium chloride prism, infrared spectrophotometer. For most of the materials, potassium bromide pellets (0.1 gram) containing 1% of the compound were prepared and the spectra obtained using the Wilks Scientific Corp. Mini-Press and slide holder. For two liquids (compounds 42 and 61), the spectra were obtained through a capillary film (0.01-mm. thickness). For compound 21, the spectrum was obtained as a 40% Nujol mull (0.01-mm. thickness), a 1% chloroform solution (0.25-mm. thickness), as well as a KBr pellet.

Method *A*. The anhydride (0.2 mole) was dissolved in 200 ml. of benzene while stirring and heating to 55° C. A solution of 0.2 mole of the desired amine in 200 ml. of benzene was added in a slow stream over a period of 10 to 15 minutes while stirring and maintaining the reaction mixture at 55° C. After all of the amine solution was introduced, the reaction mixture was stirred and heated at 55° to 70° C. for 1 hour. In some instances, a small portion was then removed, the benzene evaporated, and the residual solid used as seed. On cooling the reaction mixture to 10° C. and seeding, the product precipitated and was isolated by filtration. An analytical sample was obtained by recrystallization from an appropriate solvent.

Method *A1*. Same as method *A* except the amine was added as a solid to the benzene (200 ml.) solution of the anhydride.

Method *A2*. Same as method *A1* except the anhydride was dissolved in 400 ml. of benzene.

Method *B*. The reaction was run as described in method *A* except the anhydride and 4-nitroaniline were each dissolved in 150 ml. of methyl ethyl ketone. The reaction mixture was stirred at 70° C. for 6 hours and allowed to stand overnight at 25° C. The product was separated by filtration, reslurried in 150 ml. of methyl ethyl ketone, again separated by filtration, and dried.

Method *C*. Similar to method *A* except the anhydride was dissolved in 100 ml. of acetone; the amine, in 50 ml. of acetone. After stirring the reaction mixture for 2 hours at reflux, a small portion was removed, the acetone evaporated, and the residual solid used as seed. After adding 150 ml. of water, the reaction mixture was seeded and cooled overnight at 10° C. The product was separated by filtration and recrystallized from an appropriate solvent.

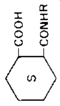
Method *D*. The cis substituted carbamoyl-carboxylic acid was melted, then stirred, and heated at a temperature about 20° C. above its melting point for a period of 1 hour while applying a vacuum (200 mm. of Hg) to remove the liberated water. The resulting product was cooled and recrystallized from an appropriate solvent or, if a liquid or low melting solid, distilled at reduced pressure.

Method *E*. The cis substituted carbamoyl-carboxylic acid (0.07 mole), 28.6 grams (0.28 mole) of acetic anhydride, and 2.8 grams (0.034 mole) of sodium acetate were mixed and allowed to stand overnight at 25° C. The reaction mixture was then stirred and heated at 90° C. for 1 hour and poured onto crushed ice (about 75 grams) whereupon the product crystallized. After separating the product by filtration, it was washed with distilled water and dried. Two of the three compounds prepared by this method were further purified by recrystallization from ethanol.

ACKNOWLEDGMENT

The authors thank J.C. Edwards and J.L. O'Sullivan for the elemental analyses, and O.E. Kinast for assistance in interpreting the infrared spectral analyses.

Table I. *cis*-2-(Substituted-carbamoyl)cyclohexanecarboxylic Acids



Compound No.	R	Method	Yield, %	Recryst. Solvent	M.P., ° C.	Formula	Analyses, % Carbon Calcd.	Carbon Found	Hydrogen Calcd.	Hydrogen Found	Nitrogen Calcd.	Nitrogen Found
1	Allyl	*A*	81	Benzene	85-6	$C_{11}H_{17}NO_3$	62.5	62.8	8.11	8.06	6.63	6.45
2	*tert*-Butyl	*A*	85	Ethanol	128.5-30	$C_{12}H_{21}NO_3$	63.4	63.7	9.31	9.65	6.16	6.32
3	Hexyl	*A*	93	Acetone-water	112-13	$C_{14}H_{25}NO_3$	65.8	65.7	9.87	9.91	5.49	5.35
4	Dodecyl	*A*	85	Benzene	105-6	$C_{20}H_{37}NO_3$	70.7	70.2	11.0	11.0	4.13	4.05
5	Octadecyl	*A2*	90	Ethanol	106-8	$C_{26}H_{49}NO_3$	73.7	74.0	11.7	11.7	3.31	3.34
6	Phenyl[a]	*A*	88	Acetone-water	171-2	$C_{14}H_{17}NO_3$	68.0	68.2	6.93	7.05	5.66	5.75
7	2-Chlorophenyl	*A*	93	Ethanol	175-6	$C_{14}H_{16}ClNO_3$	59.7	59.7	5.73	5.95	4.97	4.68[b]
8	4-Chlorophenyl[c]	*A*	94	Ethanol	180-1	$C_{14}H_{16}ClNO_3$	59.7	59.4	5.73	5.70	4.97	4.95[d]
9	3,4-Dichlorophenyl	*A*	75	Acetone-water	170-1	$C_{14}H_{15}Cl_2NO_3$	53.2	53.3	4.78	4.95	4.43	4.33[e]
10	4-Ethylphenyl	*A*	97	Ethanol	159-60	$C_{16}H_{21}NO_3$	69.8	69.7	7.69	7.76	5.09	5.08
11	4-Methoxyphenyl	*A*	97	Ethanol	170.5-2	$C_{15}H_{19}NO_4$	65.0	64.8	6.91	7.00	5.05	5.02
12	4-Nitrophenyl	*B*	44	. . .	210-11	$C_{14}H_{16}N_2O_5$	57.5	57.3	5.52	5.49	9.59	9.93
13	4-(Ethoxycarbonyl)phenyl	*A*	99	Ethanol	160-1	$C_{17}H_{21}NO_5$	63.9	63.7	6.63	6.60	4.39	4.43
14	1-Naphthyl	*A*	89	Ethanol	177-8	$C_{18}H_{19}NO_3$	72.7	73.0	6.44	6.58	4.71	4.70
15	2-Naphthyl	*A*	94	Ethanol	182-3	$C_{18}H_{19}NO_3$	72.7	72.9	6.44	6.54	4.71	4.69
16	Furfuryl	*A*	93	Benzene	124-5	$C_{13}H_{17}NO_4$	62.1	62.1	6.82	6.87	5.57	5.60
17	2-Pyridyl	*A*	79	Acetone	138-9	$C_{13}H_{16}N_2O_3$	62.9	62.8	6.50	6.45	11.3	11.3
18	3,4-Dimethyl-5-isoxazolyl	*A1*	67	Methanol-water	149-50	$C_{13}H_{18}N_2O_4$	58.6	58.6	6.81	7.01	10.5	10.5
19	Cyclohexyl	*A*	96	Ethanol	164-5	$C_{14}H_{23}NO_3$	66.4	66.3	9.15	9.41	5.53	5.52

[a] Ref. (*9, 24*), m.p., 170-1° C. [b] Chlorine, %: Calcd., 12.6. Found, 12.6. [c] Ref. (*14, 15*), m.p., 180-1° C. [d] Chlorine, %: Calcd., 12.6. Found, 12.5. [e] Chlorine, %: Calcd., 22.4. Found, 22.6.

Table II. Infrared Spectral Data (KBr Pellets)

Compound No.	Functional Group Absorption, Microns
2	2.98 M (NH); 6.18 S (Amide I); 6.47 S (Amide II); 3.0-4.0 M, 5.88 S (COOH).
4	2.98 M (NH); 6.12 S (Amide I); 6.52 S (Amide II); 3.0-4.0 M, 5.92 S, 7.85 M, 10.3-11.0 W (COOH); 13.82 W (CH_2 rocking).
10	2.96 M (NH); 6.10 S (Amide I); 6.55 S (Amide II); 3.0-3.6 S, 5.85 S (COOH); 5.27 W, 12.08 S (1,4-disubstd. phenyl).
12	3.02 M (NH); 5.95 S (Amide I and/or COOH); 6.45 S (Amide II); 6.66 S, 7.50 S (NO_2); 3.0-4.0 M (COOH); 5.20 W, 11.68 M (1,4-disubstd. phenyl).
16	2.99 M (NH); 6.10 S (Amide I); 6.52 S (Amide II); 3.0-4.0 M, 5.86 (COOH); 8.68 W, 9.25 W, 9.84 W (2-substd. furan).
17	6.0 S (Amide I); 6.53 S (Amide II); 3.75-4.5 M, 4.7-5.5 M (H^+); 6.21 S, 6.32 S, 6.98 S, 12.86 S (2-substd. pyridine).

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RECEIVED for review June 12, 1967. Accepted October 16, 1967. Material supplementary to this article has been deposited as Document number 9693 with the ADI Auxiliary Publications Project, Photoduplication Service, Library of Congress, Washington, D. C. 20540. A copy may be secured by citing the Document number and by remitting $1.25 for photoprints, or $1.25 for 35mm. microfilm. Advance payment is required. Make checks or money orders payable to Chief, Photoduplication Service, Library of Congress.