Registry No.—Oxalic acid, 144-62-7; chromic acid, 13530-68-2.

References and Notes

(1) Part VI: F. Hasan and J. Roček, *J. Amer. Chem. Soc.*, **96**, 534 (1974).
(2) This investigation was supported by the National Science Foundation.
(3) V. Srinivasan and J. Roček, *J. Amer. Chem. Soc.*, **96**, 127 (1974).
(4) (a) F. Hasan and J. Roček, *J. Amer. Chem. Soc.*, **94**, 9073 (1972); (b) F. Hasan and J. Roček, *Tetrahedron*, **30**, 21 (1974).
(5) In the limiting case, when $k_4[\cdot CO_2H] \gg k_2[CR(VI)]$, all chromium(VI) should be reduced directly to chromium(III) and, consequently, no chromium(V) formation should be observed.
(6) A bimolecular free radical disproportionation reaction $2\cdot CO_2H \rightarrow CO_2 + HCO_2H$ would fit the results of the kinetic study equally well; however, we were unable to detect any formic acid among the reaction products.

Conformational Analysis. CV. The Syn-Diaxial Methyl/Carboethoxy Interaction[1,2]

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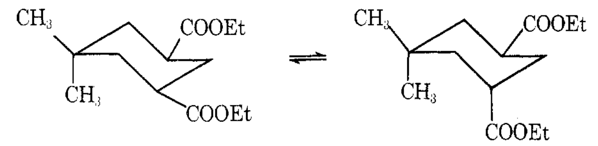
The cis and trans isomers of diethyl 5,5-dimethyl-1,3-cyclohexanedicarboxylate were prepared and equilibrated in alcohol in the presence of ethoxide ion at temperatures ranging from 23 to 102°. For the reaction trans ⇌ cis, the following thermodynamic parameters were determined: $\Delta G° = -2.44$ kcal/mol, $\Delta H° = -2.98 \pm 0.30$ kcal/mol, and $\Delta S° = -1.84 \pm 0.60$ eu. These numbers permit us to assign the syn-diaxial CH_3/COOEt interaction energy as 3.2 kcal/mol.

Because of their simplicity, cyclohexane rings have been an important foundation in conformational studies.[3] The conformational energies of all of the common substituents, and many less common ones, on a cycohexane ring are now pretty well known.[4] Surprisingly, data on systems which contain two syn-axial groups are very sparse. The systems for which data are available seem to be limited to OH/OH ($\Delta G° = 1.9$ kcal/mol[5]), OAc/OAc ($\Delta G° = 2.0$ kcal/mol[6]), CH_3/OH ($\Delta G° = 1.9$–2.4 kcal/mol[7]), CH_3/CH_3 ($\Delta G° = 3.7$ kcal/mol[8]), Cl/Cl ($\Delta G° = 5.5$ kcal/mol[9]), CH_3/Br ($\Delta G° = 2.2$ kcal/mol[10]), CH_3/F ($\Delta G° = 0.37$ kcal/mol[11]), and CH_3/X ($\Delta G° > 1.0$ kcal/mol for X = Cl, Br, and I[11]). The present paper is concerned with a determination of the value for the syn-diaxial CH_3/COOEt interaction.

To measure the interaction in question, the equilibrium between the cis and trans isomers of diethyl 5,5-dimethyl-1,3-cyclohexanedicarboxylate (1) was studied in alcoholic solution in the presence of base at temperatures ranging from 23 to 102°.



1e **1a**

One might question whether or not this equilibrium would measure simply a steric effect. After all, the carboethoxyl groups are polar groups, and they change their relative distance and orientation in the epimerization. The question is not easy to answer theoretically, because the charge distribution in a carboethoxyl group is complicated, and various conformational isomers are possible, which differ by rotations about the ester groups. However, it is known experimentally that the enthalpy of isomerization of diethyl 1,3-cyclohexanedicarboxylate[12] does not differ significantly from that of ethyl carboxylate or from those of the ethyl 4-alkylcarboxylates.[13]

Results and Discussion

Synthesis. Compound **1** presented some unusual synthetic problems, since the axial methyl group obviated many of the usual condensation routes to this type of compound. The synthetic sequence used is shown. The synthesis of **6** by this method has been previously reported[14] and will not be discussed here. Treatment of **6** with base, followed by acidification, rapidly effects a decarboxylative elimination to yield the unsaturated tricarboxylic acid **7**. An examination of Dreiding models points out the great steric crowding which exists in **6**, and the rapid decarboxylative elimination of the tetraacid of **6** probably reflects the large decrease in steric repulsion in the product. An interesting aspect of the unsaturated triacid **7** is its inability to undergo facile hydrogenation at

$$\underset{\mathbf{2}}{C_2H_5OCH{=}C(CO_2C_2H_5)_2} \xrightarrow[H_2]{PtO_2}$$

$$\underset{\mathbf{3}}{C_2H_5OCH_2CH(CO_2Et)_2} \xrightarrow{\Delta} \underset{\mathbf{4}}{CH_2{=}C(CO_2Et)_2}$$

$$\mathbf{4} + \underset{\mathbf{5}}{(CH_3)_2C{=}CHN(CH_3)_2} \xrightarrow{\Delta}$$

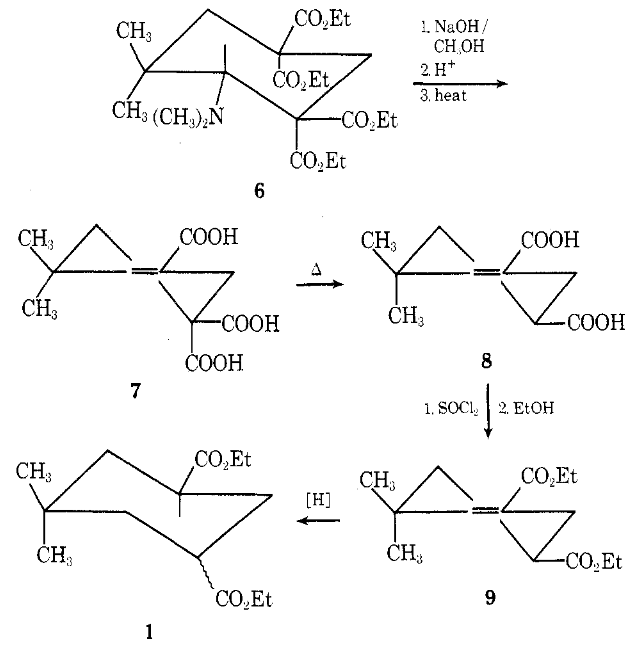


Table I
Equilibration Data for *trans-* ⇌ *cis*-Diethyl 5,5-dimethyl-1,3-cyclohexanedicarboxylate

Temp, °C	% cis[a]	σ^b	$-\Delta G°$, kcal/mol[c]
23 ± 2	98.59 (7)	0.26	2.50
52	97.64 (3)	0.27	2.40
56	97.15 (7)	0.21	2.31
70	96.49 (3)	0.35	2.27
76	96.57 (4)	0.32	2.32
102	95.29 (4)	0.32	2.24
23.2	98.57 (3)	0.32	2.49
56.5	97.55 (8)	0.29	2.41
78.5	96.68 (7)	0.08	2.36
100	95.74 (7)	0.37	2.31

[a] Number of independent runs in parentheses. [b] Standard deviation of % cis data. [c] Equilibrium approached from the trans side for the first six entries in Table I, and from the cis side for the remaining four.

Table II
Calculated Thermodynamic Parameters for the Trans ⇌ Cis Equilibration

$\Delta G°$, kcal/mol	$\Delta H°$, kcal/mol	$\Delta S°$, cal/deg mol
−2.50[a]	−3.31 (±0.3)[a,c]	−2.78 (±0.8)[a,c]
−2.44[b]	−2.98 (±0.3)[b,c]	−1.84 (±0.6)[b,c]

[a] Including room temperature data. [b] Excluding room temperature data. [c] Standard statistical methods were used.[16]

room temperature (as the triester) despite the fact that the corresponding unsaturated diester **9** was readily reduced to **1** under these conditions. Apparently in the case of the unsaturated triester there is considerable steric inhibition of hydrogenation.

Separation of the isomers (**1a** and **1e**) was accomplished by gas chromatography. Each isomer so isolated was at least 99.4% pure. Assignment of the structures of the isomers was based on nmr analysis of the pure sample collected from gc, or by fractional distillation through a spinning band column.

Conformational Study. The equilibration of *cis* ⇌ *trans*-diethyl 5,5-dimethyl-1,3-cyclohexanedicarboxylate (**1**) was carried out from both sides of the equilibrium point under basic conditions at various temperatures. The results are summarized in Table I. Utilizing the usual linear relationship between ln K, $\Delta H°$, and $\Delta S°$, the thermodynamic parameters reproduced in Table II were generated.[15] The calculated entropy of −2.78 eu for the trans ⇌ cis equilibration which was obtained including the data at 23° suggests that in the trans conformation, the molecule exists to some extent in the flexible or boat form. It seems unreasonable, however, that the syn-diaxial CH_3/CO_2Et interaction is large enough to force the molecule to exist in the boat form, especially since neither the experimental nor the theoretical evidence suggests that any appreciable amount of boat is present in *trans*-1,1,3,5-tetramethylcyclohexane, in which there is an even larger syn-diaxial interaction.[8] Consequently, the values calculated for $\Delta H°$ and $\Delta S°$ using all the data seem too large. If one considers that the room temperature data represent an amount of trans isomer of only 1.4%, an amount not easily measurable by our method, then more accurate thermodynamic parameters can probably be obtained by neglecting the room temperature data as inaccurate. Ignoring this point, a least-squares fitting of the remaining data gives 2.98 kcal/mol and 1.84 eu, respectively, for the enthalpy and entropy of the cis ⇌ trans reaction.

The value of 1.84 eu calculated for the entropy of the cis ⇌ trans equilibrium is slightly higher than (but within the experimental error of) the value of 1.38 eu predicted on the basis of a *dl* pair in the trans isomer. This may be attributable to experimental error or may be characteristic of the equilibrium. A possible explanation for the higher entropy in the trans isomer would be if the number of rotational conformers of the ester group is restricted in the cis isomer with respect to the trans. Normally, the entropy of an equatorial group might be expected to be higher than the entropy of an axial group, since the rotation of the axial group is hindered by the syn-diaxial interaction. However, in the case of the cis diester, the ester groups will attempt to align themselves so as to minimize dipole–dipole interactions and consequently the rotation of the ester groups in the cis isomer will be to some extent interdependent. If this argument is correct, then the entropy of the cis ⇌ trans equilibrium will be larger than 1.38 eu, the value expected on the basis of a *dl* pair in the trans isomer. To the best of our knowledge, only one other equilibration has been attempted using 1,3-diesters, *i.e.*, the basic equilibration of diethyl 1,3-cyclohexanedicarboxylate.[12] In that case the entropy change was *assumed* to be just the entropy of mixing of the *dl* pair in the trans isomer.

Using the enthalpy calculated for the basic equilibration of 1,3-dicarboethoxy-5,5-dimethylcyclohexane (**1**), the conformational enthalpy of the syn-diaxial methyl/carboethoxy interaction can be readily calculated. The enthalpy calculated for the trans ⇌ cis equilibrium is in reality the sum of the syn-diaxial interactions in the trans isomer less those in the cis isomer. Assuming additivity of interactions, this relationship can be expressed as follows.

$$\Delta H°_{\text{equil}} = -H°_{\text{trans}} + H°_{\text{cis}}$$

$$\Delta H°_{\text{equil}} = -(CH_3/CO_2Et + CH_3/H + CO_2Et/H) + (2\,CH_3/H)$$

Using experimentally known values of 0.8 and 0.6 kcal/mol for the syn-diaxial CH_3/H and CO_2Et/H interactions, respectively,[4a] and omitting the room temperature data point, the syn-diaxial CH_3/CO_2Et interaction is calculated to be 3.12 kcal/mol.

Experimental Section

1,1-Dicarboethoxyethylene (4). Ninety-five grams of **3** (prepared by catalytic reduction of **2**) was slowly heated above 150°, until **4** began to distil. The yield was 85% of pure **4**, bp 210–226° [lit. bp 210–216° (730 mm)].[17] This compound will dimerize (or polymerize) very rapidly, but can be stored for extended periods in the refrigerator. The monomer can be regenerated from the dimer (or polymer) by heating with a fused salt bath at 250°. The monomer exhibits olefinic stretching vibrations in the infrared region at *ca.* 1630 cm^{-1}.

2-Methyl(*N*,*N*-dimethylamino)propene (5).[18] Fifty-six grams of isobutyraldehyde was dissolved in 100 ml of xylene and charged into a high-pressure bomb. To this solution was added 30 g of anhydrous potassium carbonate (granular) and the bomb was stoppered and cooled to Dry Ice–acetone temperature. To the cooled bomb was added 37 g of previously cooled dimethylamine (anhydrous). *Caution:* Cooling ampoules of dimethylamine at low temperatures can be hazardous, and it is recommended that the ampoules be cooled in an ice–water mixture (*not Dry Ice!*) before opening. The bomb was sealed, shaken, and heated to 150° for 20 hr. It was then cooled as before and opened. The mixture was filtered to remove the salts, and the filtrate was distilled to yield **5** (67%), bp 88–90° (lit. bp 88–89°). The infrared spectrum was consistent with the required enamine.

1,1,3,3-Tetracarboethoxy-4-(*N*,*N*-dimethylamino)-5,5-dimethylcyclohexane (6).[10] To 58.03 g of **4** (distilled immediately before using and stabilized with a pinch of hydroquinone) under nitrogen was added 17.86 g of enamine **5**. On stirring, the temperature of the mixture rose to *ca.* 100° and then began to fall. The solution was then heated at 180° for 12 hr. Distillation afforded a high-boiling fraction, bp 185-188° (1-2 mm), which proved to be the desired tetraester 6 [lit.[14] bp 165-175° (1 mm)], yield 41.3%. The molecular weight as determined by mass spectral analysis was 443 (calcd 443.5). Additional purification can be accomplished by column chromatography on silica (J. T. Baker 3405) using benzene and ethyl acetate-benzene mixtures as the eluting solvents.

1,5-Dicarboethoxy-3,3-dimethylcyclohexene (9) Five grams of 6 in 10 ml of metanol was added to a previously prepared solution of 10 g of sodium hydroxide in 100 ml of methanol. The mixture was refluxed for 4 hr, with the gradual precipitation of a white solid. The solution was cooled in an ice bath and acidified to pH 1 with dilute sulfuric acid. The methanol was evaporated slowly and the residual salts were dissolved in 20 ml of water. The organic acid was recovered from the aqueous solution by continuous extraction with ether. The ethereal solution was dried over magnesium sulfate and filtered, and the ether was evaporated to yield 2.4 g of 7. Although 7 could be readily isolated and identified as its triethyl ester if the acidification was carried out at low temperatures, it was more convenient to heat 7 *in situ* to 180-200° at 1 mm for 6 hr with evolution of CO_2 to obtain 8 directly. After heating, the residue was cooled to room temperature, and 20 ml of thionyl chloride was added. The thionyl chloride solution was refluxed gently for 1 hr, or until the residue had dissolved, and any excess thionyl chloride was removed by distillation. The residue was allowed to cool and an excess of ethanol was added. The excess ethanol was evaporated and the diester olefin was distilled, bp 120-125° (5 mm), to yield 47% of the unsaturated diester 9. The nmr spectrum did not lend itself well to integration, but is consistent with the desired compound. The infrared spectrum exhibited characteristic olefinic vibrations at *ca.* 1670 cm^{-1}

Anal. Calcd for $C_{14}H_{22}O_4$: C, 66.11; H, 8.72. Found: C, 66.22; H, 8.68.

Diethyl 5,5-Dimethylcyclohexane-1,3-dicarboxylate (1). Four grams of 9 was dissolved in 20 ml of absolute ethanol and 1 g of 84% platinum oxide was added. The mixture was hydrogenated on a Parr hydrogenator until an equivalent amount of hydrogen had been absorbed. The catalyst was removed by filtration through Celite, and the solvent was evaporated to yield quantitative amounts of crude 1.

The crude mixture was separated on a Nester-Faust spinning-band column into two major components. The higher boiling component, bp 130-132° (5 mm), representing 93% of the product, was collected in three fractions. The first fraction was shown by nmr analysis to contain *ca.* 70% trans and 30% cis diester. The third fraction contained *ca.* 77% cis and the remainder trans diester and the second fraction about 50% of each isomeric diester. Fraction 2 was analyzed.

Anal. Calcd for $C_{14}H_{24}O_4$: C, 65.60; H, 9.44. Found: C, 65.70; H, 9.38.

Mass Spectral Analysis. The mass spectrum gave the molecular weight as 256 g/mol (calcd 256.3 g/mol).

Nmr Analysis. The first and third fractions from the spinning band separation exhibited the following patterns (Table III).

Separation of Cis and Trans Diesters. Using gas chromatography (12 ft, 10% Carbowax 20M/Chromosorb W at 170° and 150 ml/min helium) it was possible to separate the isomers and obtain each in at least 99.38% purity, as measured using a flame ionizing detector.

Equilibration Conditions. The esters were equilibrated from both sides of the equilibrium point at temperatures ranging from 233 to 102° using a constant-temperature bath. A standard solution of sodium ethoxide was prepared by dissolving 1 g of clean sodium in 50 ml of dry ethanol. Two milliliters of this solution was transferred to a small combustion tube (16 × 1 cm) and 10 ± 1 mg of diester mixture was added. The combustion tube was fitted with a drying tube, cooled, and sealed. The tube was then heated at the desired temperature for a period of time, which was not less than 3 days. At the end of the equilibration period, the tubes were rapidly quenched in an ice-water bath, opened, and poured into 10 ml of a 6 *N* HCl solution. The pH was checked to ensure that the solution was acid and the aqueous solution was extracted with three 10-ml portions of diethyl ether. The ethereal extracts were washed with a saturated solution of sodium carbonate and dried over magnesium sulfate. Filtration of the solution and evaporation of the solvent gave the equilibrated diester mixture, which was analyzed as below.

Table III

Ppm	Moiety	Integration Theor	Integration Actual
	1st Fraction (Mostly Trans)		
4.1 (q)	OCH_2CH_3	1.0	1.0
2.7 (m)	$CHCO_2C_2H_5$	0.5	0.47
1.85 (t)	CH_2	0.5	0.47
1.58 (d)	CH_2	1.0	0.9
1.2 (t)	OCH_2CH_3	1.5	1.6
1.0 (s)[a] 0.95 (s)[a] 0.89 (s)[b]	CH_3 (gem)	1.5	1.4
	3rd Fraction (Mostly Cis)		
4.1 (q)	OCH_2CH_3	1.0	1.0
2.8-1.4	CH, CH_2	3.5	3.6
1.2 (t) 1.0 (s)[a] 0.95 (s)[a] 0.89 (s)[b]	OCH_2CH_3 CH_3 (gem)	1.5	1.6

[a] Represents nonequivalent geminal methyls in cis isomer with a separation of 2-3 Hz. [b] Represents the trans isomer.

Analysis of Equilibrated Mixtures. The mixture of diesters obtained above was dissolved in 1-3 drops of diethyl ether or hexane and chromatographed on a Perkin-Elmer F-11 flame ionizing gas chromatograph using a 50-ft capillary column (Carbowax 20M, S.C.O.T.C.) or on a Perkin-Elmer Model 881 Gas Chromatograph using a 12 × 0.125 in. column (3.6% FFAP and 2.4% EGSP-2 on Chromosorb P[19]) at 210°. The relative amount present was determined by the triangulation method.

Registry No.—*cis*-1, 51593-44-3; *trans*-1, 51592-65-5; 6, 51592-66-6; 7, 51592-67-7; 8, 51592-68-8; 9, 51592-69-9.

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