

## Aluminum Chloride Catalyzed Diene Condensation. III.<sup>1,2</sup> Reaction of *trans*-Piperylene with Methyl Acrylate

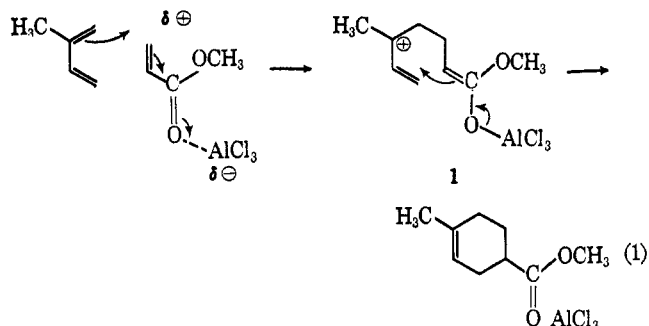
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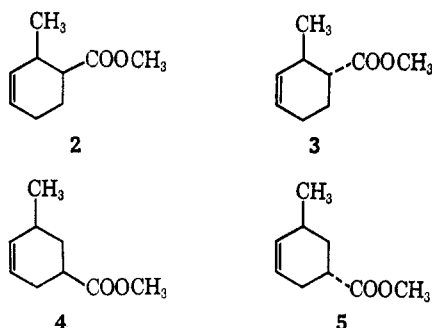
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The kinetically controlled ratio of the four isomers, 2–5, formed by the aluminum chloride catalyzed and uncatalyzed reactions of *trans*-piperylene and methyl acrylate was determined. The catalyzed reaction is highly *cis* selective and is position selective, whereas the uncatalyzed reaction is not. The relative rates of butadiene and *trans*-piperylene toward methyl acrylate were determined to obtain the partial rate factors. Implications of these results are discussed.

In paper I<sup>3</sup> of this series the substituent effect of the methyl group on the rate and orientation of the reactions of isoprene and methyl acrylate in both the aluminum chloride catalyzed and uncatalyzed reactions was reported, and the large accelerating effect of the methyl group was explained, in effect, by stabilization of the electron-deficient center in the proposed transition model 1 (eq 1). This study is now extended in the



present article to the similar case of *trans*-piperylene-methyl acrylate reaction, where the four isomeric products, 2–5, can be formed and therefore the stereo-



chemical selectivity is of additional concern. The stronger adherence to the Alder *endo* rule of the catalyzed reaction with cyclopentadiene has already been reported.<sup>1,4</sup> It is of mechanistic interest to investigate whether the analogous *cis* selectivity is also prominent in the reaction with an acyclic diene.

### Results and Discussion

The reactions were carried out in the same way as was described previously.<sup>3</sup> The analysis of the propor-

(1) Paper II: T. Inukai and T. Kojima, *J. Org. Chem.*, **31**, 2032 (1966).

(2) Presented in part at the 19th Annual Meeting of the Chemical Society of Japan, Yokohama, Japan, March 1966; Abstract, III, p 80. The Diels-Alder reaction of piperylene and methyl acrylate has been reported by J. S. Meek and J. W. Ragsdale [*J. Am. Chem. Soc.*, **70**, 2502 (1948)].

(3) T. Inukai and T. Kojima, *J. Org. Chem.*, **31**, 1121 (1966).

(4) J. Sauer and J. Kredel, *Tetrahedron Letters*, 731 (1966).

tion of 2:3:4:5 in the product was made in the following way. The gas-liquid partition chromatographic (glpc) analysis of the reaction product allowed us to determine the ratio of 2:3:(4 plus 5). For partial cross checking of this result the ratio of (2 plus 3):(4 plus 5) was determined by an independent method: the reaction product was dehydrogenated by passing over palladium on asbestos<sup>3</sup> at 340–350° to give a mixture of *o*- and *m*-toluates and this mixture was analyzed by glpc. The agreement between these two determinations is quite satisfactory (Table I). The per cent of 4 could be determined by glpc of the hydrogenation product, *i.e.*, the *cis* and *trans* mixture of methyl 2- and 3-methylcyclohexane-1-carboxylates. These data allowed us to calculate the per cent of 5; hence the ratio of the four isomers could be determined as is summarized in Table I.

TABLE I

ISOMER DISTRIBUTIONS OF THE PRODUCTS FROM REACTIONS OF *trans*-PIPERYLENE AND METHYL ACRYLATE (OR ACRYLIC ACID)

	Reaction Conditions			
	Catalyzed <sup>a</sup>	Uncatalyzed <sup>b</sup>		
Temp, °C	10–20	25	120	120 <sup>c</sup>
Piperylene, mole	1.47	0.2	0.3	0.56
Methyl acrylate, mole	1.47	0.16	0.3	0.78
Time	3 hr	70 days	6 hr	7 hr
Yield, %	50	39	53	52
Product Distribution				
(2 + 3):(4 + 5) <sup>d</sup>	98:2	90:10	84:16	89:11
(2 + 3):(4 + 5) <sup>e</sup>	98:2	90:10	83:17	88:12
2:3 <sup>f</sup>	95:5	57:43	54:46	64:36
4:5 <sup>g</sup>	Mostly <i>cis</i>	73:27	66:34	62:38

<sup>a</sup> In benzene (150 ml) in the presence of 0.15 mole of anhydrous aluminum chloride. <sup>b</sup> Room-temperature (*ca.* 25°) reaction in a sealed tube, and 120° reactions in a stainless steel autoclave. Hydroquinone was added. <sup>c</sup> Reaction of free acrylic acid. <sup>d</sup> By glpc analysis of the aromatization products. <sup>e</sup> By glpc analysis of the cyclohexenecarboxylates. <sup>f</sup> By glpc analysis of the cyclohexanecarboxylates.

The stronger adherence of the catalyzed reaction to the Alder *endo* rule is observed in this case too. This fact shows that the enhanced *endo* selectivity found in the cyclopentadiene reaction should be ascribed not to the increased steric hindrance between the complexed carboxylate group and the methylene hydrogen but to the increased  $\pi$  interactions between the unsaturated centers of addends in the transition state, as was discussed in the previous paper.<sup>1</sup>

Kinetic control of the product ratio is shown by the following observations. The equilibria, 2  $\rightleftharpoons$  3 and 4  $\rightleftharpoons$  5, under alkaline epimerizing conditions, favor the

*trans* isomers **3** and **5**, respectively. Therefore the predominant *cis* products, **2** and **4**, are the thermodynamically less stable stereoisomers. It is also shown that the product of the catalyzed reaction was not changed in its isomeric composition on heating at 120° for 6 hr; hence epimerization of the reaction products, which would tend to increase the content of the *trans* isomers, does not occur to any appreciable extent under the conditions of diene condensation.

The higher stability of **5** over **4** is rather interesting because the analogy with 1,3-disubstituted cyclohexanes will suggest the contrary, but the conformational analysis of the 1,3-disubstituted cyclohexenes is not unambiguous enough to regard this result as an unreasonable one.<sup>5</sup> It is gratifying that the equilibrium of methyl 3-methylcyclohexene-1-carboxylates favors the *cis* isomer in conformity with the conformational analysis.

It is of interest to note that the predominance of the *cis* over the *trans* isomer is rather poor in the uncatalyzed reaction on reference to the consensus of the Alder *endo* rule.<sup>7-9</sup> It is beyond doubt that strongest dienophiles, such as maleic anhydride and *p*-benzoquinone, show high *endo* selectivity in reactions with cyclic dienes and acyclic dienes.<sup>7-9</sup> The  $\pi$  interactions in the *endo* transition state secures the *endo* selectivity, presumably in cooperation with the steric hindrance<sup>7</sup> against the *exo* orientation in the reactions of cyclic dienes. With acyclic dienes such a steric hindrance obviously drops out; therefore it is expected that, as the  $\pi$  interactions decrease, as it may be the case with weaker dienophiles, the *endo* selectivity will fall off without much reluctance. Unfortunately this generalization is not borne out at present because of lack of quantitative data. However, it is worth noting that a boundary case of *cis* or *trans* selectivity under kinetic control has been found in the reactions between weaker dienophiles and an acyclic diene. Thus, *trans*-1-phenyl-1,3-butadiene gives with acrylyl chloride and acrylic acid almost exclusively *cis* and with acrylamide predominantly *trans*, whereas with acrylonitrile it gives almost exclusively *trans* adduct.<sup>10,11</sup> This will indicate that the weak  $\pi$  interactions may be overlaid easily as the case may be by a counteracting factor,<sup>12</sup> which is in these instances presumably a steric requirement of the phenyl group.

The faint *cis* selectivity of the uncatalyzed reaction of the present study can be rationalized from this consideration and will suggest that the Diels-Alder reactions between weaker dienophiles and acyclic dienes may give a considerable amount of the *trans* isomer.

The relative rates of piperylene *vs.* butadiene in the catalyzed and uncatalyzed reactions were determined by competitive experiments as is summarized in Table

(5) The transannular carbonyl-double bond exchange interaction in the axial carboxylate conformation, as was proposed,<sup>4</sup> is a possible reason for an extra stabilization of **5**.

(6) G. P. Kugatova-Shemyakina and Yu. A. Ovchinnikov, *Tetrahedron*, **18**, 697 (1962).

(7) K. Alder, *Ann.*, **571**, 157 (1951).

(8) J. G. Martin and R. K. Hill, *Chem. Rev.*, **61**, 537 (1961), section V.

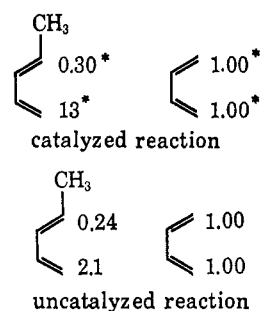
(9) A. Wassermann, "Diels-Alder Reactions," Elsevier Publishing Co., Amsterdam, 1965, Chapter 2.

(10) J. S. Meek, F. J. Lorenzi, and S. J. Cristol, *J. Am. Chem. Soc.*, **71**, 1830 (1949).

(11) J. S. Meek, B. T. Poon, R. T. Merrow, and S. J. Cristol, *ibid.*, **74**, 2669 (1952).

(12) J. A. Berson, Z. Hamlet, and W. A. Mueller, *ibid.*, **84**, 297 (1962).

CHART I  
PARTIAL RATE FACTORS



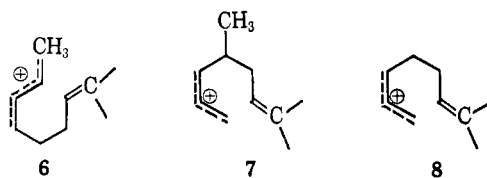
II, and the partial rate factors (prf) are shown in Chart I. The same comment as given for the case of isoprene<sup>3</sup> applies to the proposal of the prf.

TABLE II  
RELATIVE RATES OF PIPERYLENE *vs.* BUTADIENE

	Catalyzed		Uncatalyzed
	117.5	117.5	
Piperylene, mmoles	117.5	117.5	440.8
Butadiene, mmoles	1099	860.3	804.8
Methyl acrylate, mmoles	34.86	34.86	11.61
AlCl <sub>3</sub> , mmoles	5.03	4.64	None
Benzene, ml	75	75	None
Temp, °C	7-14	7-14	25
Time	3 hr	3 hr	52 days
Yield, g	3.1	2.9	0.70
Product ratio <sup>a</sup>	0.63	0.90	0.65
Relative rate <sup>a</sup>	6.12	6.82	1.19

<sup>a</sup> Piperylene to butadiene.

Adopting the same electronic reorganization steps, eq 1, as were previously proposed for the catalyzed reaction,<sup>3</sup> the high prf of the terminal position of *trans*-piperylene may be qualitatively explained by comparing the degrees of stabilization of the electronic systems, **6**, **7**, and **8** (dotted lines). The low prf of 4 position



of *trans*-piperylene may be due to its lower ground-state energy compared with that of butadiene or the steric hindrance to the attack at the secondary carbon or both.

As will be seen from the high *endo* selectivity and the low pre-exponential factor of activation of the catalyzed reaction,<sup>13</sup> the addends approach one another in parallel biplanar arrangement in the *endo* sense with associated  $\pi$  interactions. Consequently the electronic reorganizations as shown in eq 1 should be understood to occur in this scheme of molecular events.

### Experimental Section<sup>14</sup>

**Preparation of Authentic Samples.** Methyl *cis*-2-methyl-3-cyclohexene-1-carboxylate (**2**) was prepared by esterification of *cis*-2-methyl-3-cyclohexene-1-carboxylic acid, mp 63.5-64.5° (lit.<sup>15</sup> mp 64°), with diazomethane in ether solution and had bp

(13) See succeeding paper: Inukai, T., and Kojima, T., *J. Org. Chem.*, **32**, 872 (1967).

(14) Melting points are corrected.

(15) K. Alder and W. Vogt, *Ann.*, **564**, 120 (1949).

79–79.5° (13 mm). *Anal.* Calcd for  $C_9H_{14}O_2$ : C, 70.07; H, 9.15. Found: C, 70.6; H, 9.1.

**Methyl *trans*-2-Methyl-3-cyclohexene-1-carboxylate (3).**—Compound 2 (above) was epimerized by refluxing with methanolic sodium methoxide solution for 12 hr to give a mixture of 3 and 2. An uncontaminated binary mixture of 3 (96%) and 2 (4%), bp 82° (20 mm), was obtained by preparative glpc using Carbowax 6000.

**Methyl *trans*-2-Methylcyclohexane-1-carboxylate (3').**—*trans*-2-Methylcyclohexene-1-carboxylic acid prepared by the published procedure,<sup>16</sup> mp 52° (lit.<sup>16</sup> mp 52°), was esterified with diazomethane in ether solution and had bp 79–79.5° (20 mm). *Anal.* Calcd for  $C_9H_{16}O_2$ : C, 69.19; H, 10.32. Found: C, 69.8; H, 10.6.

**Mixture of Methyl *cis*- and *trans*-2-Methylcyclohexane-1-carboxylates (2' and 3').**—*trans*-2-Methyl-4-cyclohexene-1-carboxyaldehyde<sup>16</sup> was thermally isomerized (260–270°, 2.5 hr) to a *cis* and *trans* mixture.<sup>6,17</sup> This mixture was oxidized with wet silver oxide to obtain the acid mixture. The *trans* acid was removed by filtration and the filtrate was hydrogenated with palladium-on-carbon catalyst in methanol at normal temperature and pressure. The saturated acid mixture was directly converted into the methyl esters with diazomethane in ether. Distillation afforded an uncontaminated binary mixture of 2' (58%) and 3' (42%), bp 82.2–82.5° (20 mm). *Anal.* Calcd for  $C_9H_{16}O_2$ : C, 69.19; H, 10.32. Found: C, 69.2; H, 10.6.

**Mixture of methyl *cis*- and *trans*-3-methylcyclohexane-1-carboxylates (4' and 5')** was obtained by esterification of the corresponding acid mixture, prepared by the procedure of Goering and McCarron,<sup>18</sup> and had bp 85–88° (20 mm). According to their elaborate study this acid mixture consists of  $26 \pm 5\%$  of *trans* and  $74 \pm 5\%$  of *cis* isomer. Our ester mixture exhibited glpc peaks of 35% and 65% areas, and the ratio changed to 27:73 after epimerization (*vide infra*). These results justify the assignment of the larger peak to the *cis* isomer.

**Reactions.**—The reactions of piperylene with methyl acrylate were carried out in the same way as was described previously<sup>3</sup> and the products were distilled through a simple Vigreux column, bp 103–105° (40 mm). The competitive reactions were also carried out as was previously described,<sup>3</sup> the reaction mixtures were concentrated under reduced pressure, and the concentrates were directly subjected to glpc analysis. The reaction with acrylic acid was conducted according to the procedure of Alder and Vogt,<sup>15</sup> and the product, bp 128–132° (13 mm), was converted into the methyl ester with diazomethane for glpc analysis.

**Analytical Procedures.**—The dehydrogenation to the methyl toluates was carried out by passing the vapor of the products over palladium-on-asbestos catalyst at 340–350° with the procedures

described previously.<sup>3</sup> Pure 1 gave no *m*-toluate; hence *ortho*–*meta* isomerization during this process can be ruled out. The glpc analyses were carried out with an Ohkura Model 1200 instrument. The determination of *o*- and *m*-toluates employed a 2.7 m × 5 mm i.d. copper column packed with 10 wt % Carbowax 6000 on Diasolid M (Nihon Chromato Industries Co., Ltd.) at 150°. The same column packed with 10 wt % 1,2,3-tris( $\beta$ -cyanoethoxy)propane on Diasolid M (the same supplier) was used for the cyclohexene and cyclohexane derivatives. The retention times were 10.3, 12.4, and 14.2 min for 3, overlapped 4 plus 5,<sup>19</sup> and 2, respectively, at 100° at the flow rate of helium of about 88 ml/min. The retention times for 2', 3', 4', and 5' were 11.4, 9.7, 12.5, and 10.1 min, respectively, at 80° at the flow rate of helium of about 170 ml/min. With a small injected sample (about 3  $\mu$ l), satisfactory separation of peaks due to 2, combined 4 plus 5, and 3 could be achieved when content of 4 plus 5 was small. Separation of 4' from the rest was good enough to allow us to determine the per cent of 4' in the products from uncatalyzed reactions accurately, but in analysis of the product from the catalyzed reaction the minute peak of 4' was badly overlapped by the tail of the too large 2' peak to such an extent that graphical subtraction of the tail must be made to measure the peak area due to 4'. Equal thermal conductivity of the isomers was assumed in these cases. Carbowax 6000 was used for determination of the ratio of products from butadiene and piperylene. Here use was made of the calibration curves for the peak area ratio *vs.* the molar ratio of 3-cyclohexene-1-carboxylate on one hand and the relevant mixtures of 2–5 from the piperylene reactions on the other hand.

**Epimerization Experiments.**—The product of the aluminum chloride catalyzed reaction was heated in a sealed tube at 120° for 6 hr. No change of isomer distribution was detectable by glpc analysis, showing the kinetic control of the product ratio. When the product of the uncatalyzed reaction (25°), 3.6 g, was heated in a methanolic sodium methoxide solution under reflux for a period of 7 hr to attain equilibrium, the isomer distribution (2:3:4:5) was changed to 5:85:1:9 from the original ratio of 52:38:7:3. The mixture of 4' (65%) and 5' (35%) was epimerized under the same conditions to the equilibrium mixture of 4' (73%) and 5' (27%).

**Registry No.**—2, 7605-50-7; 3, 7605-51-8; 4', 7605-52-9; 5', 7605-53-0; methyl acrylate, 96-33-3; *trans*-piperylene, 504-60-9; 3', 7605-54-1; 2', 7605-55-2; 4, 7605-56-3; 5, 7605-57-4.

**Acknowledgment.**—The authors wish to thank Mr. Takao Nakamura for his valuable technical assistance.

(16) O. Diels and K. Alder, *Ann.*, **470**, 62 (1929).

(17) I. N. Nazarov, G. P. Kugatova, and V. V. Mozolis, *Zh. Obshch. Khim.*, **27**, 2635 (1957); *Chem. Abstr.*, **52**, 7167 (1958).

(18) H. L. Goering and F. H. McCarron, *J. Am. Chem. Soc.*, **80**, 2287 (1958).

(19) Although authentic 4 and 5 were not made available, they could be assigned to the peak at this retention time (12.4 min) from the fact that their total amount (4 plus 5) calculated on the basis of this assignment quantitatively agrees with that determined from the glpc analysis of the toluates.