

INTRAMOLECULAR DIELS-ALDER REACTIONS
OF ETHYL 2,4,9-DECATRIENOATE AND 2,4,10-UNDECATRIENOATE

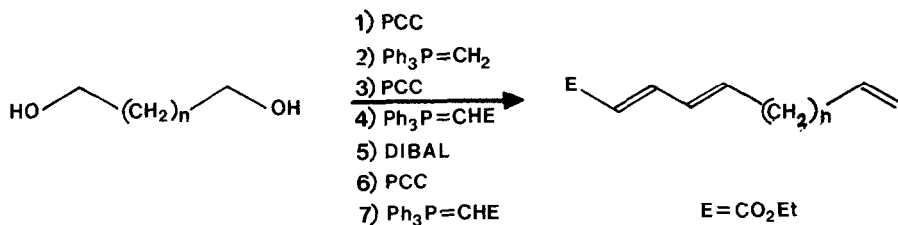
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Abstract: The title compounds undergo intramolecular Diels-Alder reactions at 180°C to give ester-substituted hydrindane and decalin ring systems, with trans/cis ratios of 43:57 and 50:50, respectively.

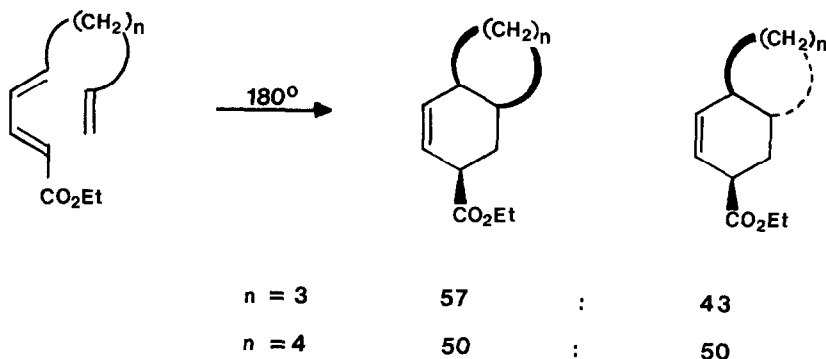
In previous communications, we have described the stereoselectivities of intramolecular Diels-Alder reactions, and have proposed a model to rationalize the variations in stereochemistries of intramolecular Diels-Alder reactions that occur upon unsymmetrical substitution of the diene or dienophile.¹ Our hypothesis is that the parent hydrocarbons react via nearly synchronous transition states, while acceptor substitution on the dienophile causes "twist" asynchronous transition structures to be favored. Substitution on the terminus of the diene also has an effect on the synchronicity of the reaction: donor substituents on the diene promote trans stereoselectivity.¹ Acceptor substituents on the terminus of the diene should have an effect in the same direction, producing twist-asynchronicity and favoring the trans adduct. However, the influence of an acceptor substituent on the diene should be relatively small, since even with the unsubstituted reactants, the diene is slightly nucleophilic with respect to the dienophile.²

We have investigated the intramolecular cycloadditions of nonatriene and decatriene substituted by an ester group at the peripheral¹ terminus of each diene. The trienoates systems, 1 and 2, were synthesized by the standard techniques outlined below.^{3,4}



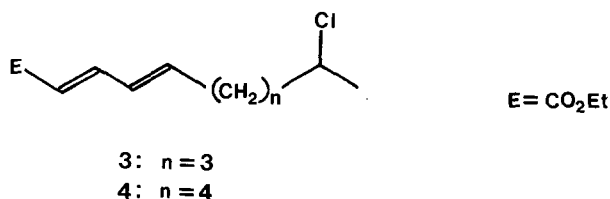
Cycloadditions of the purified trans,trans dienes were carried out at 180° in a sealed tube in cyclohexane

solvent with a triene concentration of about 5 mg/ml. Products ratios were determined by analytical glc,^{5a} and pure products were isolated by preparative glc.^{5b} The stereochemistries of the products were established by nmr spectroscopic studies of the separated adducts.⁶



The reactions of **1** and **2** proceed at rates similar to those of the parent hydrocarbons. In the reaction of **1**, the cis product is slightly favored. The cis:trans product ratio of 57:43 at 180°C corresponds to a 0.3 kcal/mol lower free energy of activation for the formation of the cis product than for the formation of the trans product. By comparison, there is a 1.0 kcal/mol preference for formation of the cis adduct in the parent hydrocarbon reaction. Thus, substitution of the diene terminus by an ester lowers the free energy of activation of formation of the cis product by 0.7 kcal/mol relative to that for the trans adduct. Ester substitution of the dienophile has a larger (1.3 kcal/mol) effect,¹ so that the trans product is favored. Compound **2** gives a 50:50 mixture of cis and trans adducts, whereas the hydrocarbon favors the cis product by 0.3 kcal/mol.¹ Ester substitution on the dienophile peripheral terminus also results in a 50:50 mixture of cis and trans adducts.

We have also attempted to catalyze the reactions of the diene-substituted esters, **1** and **2**, with Lewis acid catalysts. Intramolecular Diels-Alder cycloadditions, with ester substituents on the alkene terminus, have been catalyzed by Lewis acids such as diethyl aluminum chloride, ethyl aluminum dichloride, boron trifluoride etherate, aluminum chloride, and titanium tetrachloride.⁷ Attempted catalysis of cycloadditions of **1** and **2** with these substances were uniformly unsuccessful. No reaction took place with the first three catalysts after 3-4 days at room temperature. Upon increasing the reaction temperature to 40°C, vigorous polymerization of **1** and **2** occurred within one hour, and no cycloadducts were detected. When aluminum chloride or titanium tetrachloride were used as catalysts, no reaction of either **1** or **2** was observed after several days at room temperature in methylene chloride solvent. Upon standing for longer periods of time, both **1** and **2** gave small amounts of products arising from HCl addition to the isolated double bond. Evidently, these products, **3** and **4**, are the consequence of small amounts of moisture invading the reaction mixture.



As suggested in the introduction, an ester on the diene produces the same type of change in stereoselectivity as an ester substituent on the alkene, but the effect of diene substitution is considerably smaller than the effect of alkene substitution. This is consistent with the expected smaller effect of an electron-withdrawing substituent upon the diene than upon the alkene, because of the nucleophilic character of the diene in a Diels-Alder reaction,² and because of the relatively minor influence of an electron-withdrawing substituent on the diene HOMO coefficients and energies.⁸ The substitution of the diene terminus by an ester will cause twist asynchronicity in the sense described in a previous communication,¹ but since the ester perturbation of the diene HOMO is quite small, the degree of twist asynchronicity is smaller than upon terminal substitution of the dienophile. As a consequence, *cis* adduct formation is still slightly favored in the nonatriene case, whereas no stereoselectivity is found in the decatatriene series.

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References and Notes

(1) Brown, F.K.; Houk, K.N., *Tetrahedron Lett.*, in press. See also: Lin, Y.-T., Houk, K.N., *Tetrahedron Lett.*, in press, and Wu, T.-C.; Houk, K.N., *Tetrahedron Lett.*, in press.

(2) Sauer, J.; Sustmann, R., *Angew. Chemie Int. Ed. Engl.*, **1980**, *19*, 779.

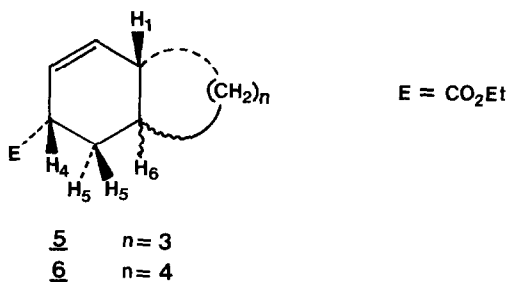
(3) All new compounds were analyzed by 300 MHz nmr spectroscopy and high resolution mass spectrometry.

(4) The Wittig reactions in steps (4) and (7), which were carried out in CH_2Cl_2 at room temperature, gave a mixture of *trans*- and *cis*-alkenes in a ratio of 9:1.

(5) (a) $10' \times 1/8''$ 10% SE-30 on Chromosorb W column; (b) 20% SE-30 on Chromosorb W column.

(6) The stereochemistries were established by the bridgehead proton couplings and allylic methine proton couplings. The following coupling constants (in Hz) are indicative of structure. **5**: *cis*-adduct (J_{16} = small coupling obscured by other couplings, J_{45ax} = 11.2), *trans*-adduct (J_{16} = 10.4, J_{45} = small couplings obscured by other couplings); **6**: *cis*-adduct (J_{16} = small coupling obscured by other couplings, J_{45ax} = 10.2), *trans*-adduct (J_{16} = 11.8, J_{45} = small coupling obscured by other couplings). Both *cis*-adducts have

H₄ axial, while H₄ is equatorial in the trans-adducts.



(7) Roush, R.; Gillis, H.R., J. Org. Chem., **1980**, 45, 4267.

(8) Houk, K.N., J. Am. Chem. Soc., **1973**, 95, 4092; Houk, K.N.; Sims, J.; Watts, C.R.; Luskus, L.J., J. Am. Chem. Soc., **1973**, 95, 7301.

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