1,3-Shift with Inversion in a Norbornadiene to Cycloheptatriene Rearrangement

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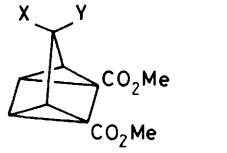
syn-Methoxynorbornadiene (**5**) rearranges thermally *via* formal 1,3-sigmatropic shift to a set of cycloheptatrienes different to those obtained from *anti*-methoxynorbornadiene (**6**); the *ca.* 95% selective migration of C-7 to the double bond *anti* to the methoxy group in both isomers suggests a preference for a 1,3-shift with inversion at C-7.

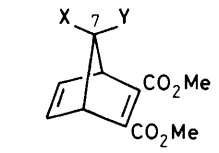
Norbornadiene rearranges to cycloheptatriene[1] above 325 °C. Bornadiene behaves similarly[2] at 270 °C, and the lack of stereospecificity in this rearrangement indicates that a biradical intermediate is involved. 7-Phenyl- and 7-alkoxynorbornadienes undergo rearrangement to cycloheptatrienes[3] at 170 °C. We describe here our observation that introduction of ester substituents at C-2 and C-3 in 7-methoxynorbornadiene leads the *syn*- and *anti*-methoxy isomers to rearrange to different cycloheptatrienes, suggesting that formal 1,3-shift occurs with inversion of stereochemistry, in agreement with the Woodward–Hoffmann rules for a concerted process. This site selectivity thus represents a useful probe of rearrangement stereochemistry in the 1,3-shift.

The norbornadienes *syn*-(**5**) and *anti*-(**6**) were prepared from quadricyclanols[4] (**1**) and (**2**) respectively, by methylation (MeI, Ag_2O in MeOH, 20 °C) and ring-opening of (**3**) and (**4**) with Pd–C in boiling EtOAc. Assignment of *syn*- and *anti*-stereochemistry was based on the long-range coupling (*J* 0.8 Hz) between H-7 and the olefinic protons in (**6**) which was absent in the *syn*-isomer (**5**). The isomers were thermolysed in degassed C_6D_6 in base-washed sealed tubes and reaction progress was followed by ^1H n.m.r. spectroscopy.

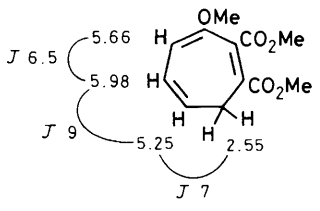
Rearrangement of the *anti*-isomer (**6**) proceeded at 160 °C (k *ca.* 1.31×10^{-4} s^{-1}) to give the cycloheptatrienes (**7**) (27%), (**8**) (16%), and (**9**) (21%). These were separated by short-column chromatography in benzene–diethyl ether (39:1). The assigned structures are supported by the ^1H n.m.r. data (δ and *J*/Hz) appended to their formulae. The placement of all three substituents on contiguous carbons in all three products indicates their origin from the norcaradiene (**10**) and cycloheptatriene (**11**); 1,5-hydrogen migration to C-3 of (**11**) gives (**7**) directly and subsequent 1,5-hydrogen shift to C-4 of (**7**) produces (**8**). Alternative 1,5-hydrogen shift to C-4 of (**11**) followed by a further 1,5-hydrogen shift leads to (**9**). The strong positional selectivity observed in the 1,3-shift leading from (**6**) to (**10**) is most easily explained if the shift proceeds with inversion. The transition state (TS) (**12**) involving close approach of the C-7 hydrogen and the migration frame would be preferred to that, (**13**), involving steric clash of the C-7 methoxy and the migration frame. That electronic factors associated with the methoxycarbonyl groups are not responsible for the positional selectivity was shown by thermolysis of the *syn*-isomer (**5**). At 160 °C this rearranged more slowly (k *ca.* 2.8×10^{-5} s^{-1}) and less cleanly than (**6**) to give a mixture of eight cycloheptatrienes which were separated by short-column chromatography into a mixture of (**14**)



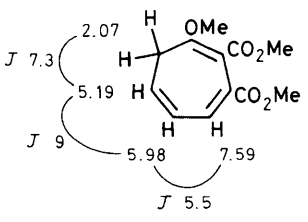
(**1**) X = H, Y = OH
(**2**) X = OH, Y = H
(**3**) X = H, Y = OMe
(**4**) X = OMe, Y = H



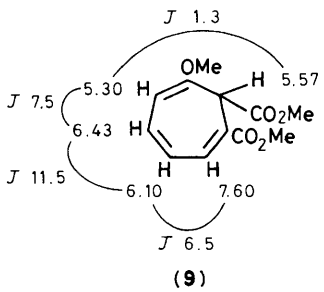
(**5**) X = H, Y = OMe
(**6**) Y = H, X = OMe



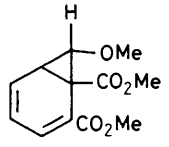
(**7**)



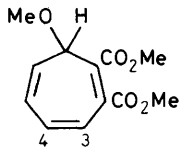
(**8**)



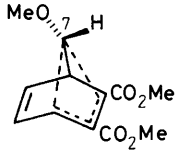
(**9**)



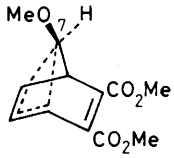
(**10**)



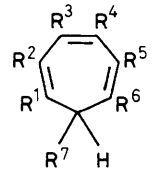
(**11**)



(**12**)

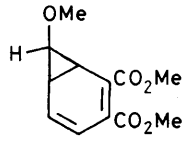


(**13**)

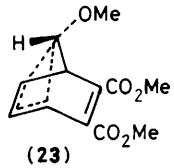


(**14**) $R^3 = R^4 = CO_2Me$, $R^1 = OMe$
(**15**) $R^7 = R^1 = CO_2Me$, $R^3 = OMe$
(**16**) $R^1 = R^2 = CO_2Me$, $R^4 = OMe$
(**17**) $R^5 = R^6 = CO_2Me$, $R^1 = OMe$
(**18**) $R^4 = R^5 = CO_2Me$, $R^2 = OMe$
(**19**) $R^7 = R^1 = CO_2Me$, $R^5 = OMe$
(**20**) $R^4 = R^5 = CO_2Me$, $R^1 = OMe$
(**21**) $R^4 = R^6 = CO_2Me$ $R^1 = OMe$

} Other R = H



(**22**)



(**23**)

and (**15**) (19%), a mixture of (**16**), (**17**), (**18**), and (**19**) (40%),† and two individual cycloheptatrienes (**20**) (2%) and (**21**) (3%). These products are readily formulated as arising from the norcaradiene (**22**) produced *via* the less hindered inversion TS (**23**); 1,5-hydrogen shifts interconvert the valence tautomer of (**22**) with the cycloheptatrienes (**14**)—(**19**), whilst norcaradiene walk rearrangements and 1,5-hydrogen shifts are required to produce (**20**) and (**21**). Only minor amounts of products derived by migration to the more substituted double bond in (**5**) (5%) and to the less substituted double bond in (**6**) (3%) were detected. These may arise *via* walk interconversion of the initially formed norcaradienes. Alternatively they may derive from suprafacial retention or non-concerted rearrangement. The preferred inversion observed for the 1,3-shifts described here is consistent with the predictions of Woodward and Hoffmann. However, preferred inversion may also characterise rearrangement through a biradical intermediate.[5] The introduction of methoxycarbonyl groups into 7-methoxynorbornadiene involves only a small acceleration of rearrangement whereas introduction of the same substituents into 7,7-dimethoxynorbornadiene allows observation of a hitherto unobserved 7,7-dialkoxynorbornadiene to cycloheptatrienone acetal rearrangement. This occurs at 45 °C whereas simple norbornadiene acetals are reported merely to extrude dialkoxycarbene at *ca.* 150 °C.[6] A dichotomy of rearrangement mechanism for 7-alkoxy- and 7,7-dialkoxy-norbornadienes is indicated by these results.

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† Mixtures were analysed by ^{1}H n.m.r. at 400 MHz with the aid of extensive spin-decoupling experiments. A singlet (or a finely spaced doublet) assigned to the proton flanked by a methoxy and a methoxycarbonyl group was characteristic of this group of cycloheptatrienes with the exception of (**19**) where there is a neighbouring proton. Structural assignments for compounds not individually isolated are tentative.

References

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