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PROPELLANES—XXXIII

CONFORMATIONS OF VARIOUS HETEROCYCLIC PROPELLANES†

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Abstract—Eu(DPM)$_3$ has been used as a shift reagent in studying the NMR spectra of various propellanes. The PDIGM program has been used to calculate the preferred conformations of these substrates.

INTRODUCTION

Crystal structures of various propellanes have been determined and these studies reveal their conformations in the solid state.[1] Knowledge regarding the relative stability of conformations of certain propellanes in solution would be useful since these compounds have been subjected to various reactions in which more[2] or less[2f] stereoselectivity has been observed. Any knowledge gained would be used to consider the steric course of the pertinent reactions. *A priori* this aspect is not expected to be an overwhelming one as the energy required for a given conformation (cyclohexene rings are usually involved) to afford another is, at most, a few kcal/mol. NMR[2c,3] and ESR[4] studies have also been carried out in order to obtain information regarding conformations of certain propellanes.

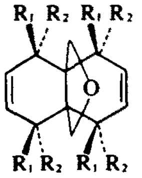
In this paper we report an extension of the work already published[2c] in which we have used a lanthanide shift reagent as a tool for conformational analysis of the propellanes **1–9**. We applied the PDIGM program[5] for determining the best fit of our spectra *vis-à-vis* simulated spectra. We intend to determine the preferred conformation of each substrate and to classify those molecules which apparently behave similarly in this respect. Incidentally and not least, evidence was presented regarding the location of the site in each substrate which coordinated with the lanthanide element.

It appears (see below) that the propellanes **1–4** belong to one conformational class whilst **6–8** belong to another. Compound **5** will be discussed separately.

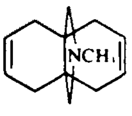
Computation method. For each of the molecules studied experimentally, a set of calculations was performed for the NMR shifts, using the PDIGM program.[5]‡ The calculated values for the shifts were dependent upon the assumed conformation, the position of the lanthanide reagent in the substrate-reagent complex, and the site of complex-formation in the substrate. The principal magnetic axis was assumed to pass through this site and the position of the lanthanide atom. Several conformations were considered and in each case an extensive search was made for the position of the lanthanide atom for which the best agreement with experimental shifts was obtained. If the substrate contained more than one potential site for complex-formation (e.g. N or O), both calculations were performed. The parameters R, d, ρ and ϕ were defined as in Ref. 5.

Since PDIGM was designed for analysis of rigid molecules we had to deal with our substrates within the framework imposed by this constraint. We are thus limited to dealing with cases in which one conformation is overwhelmingly preferred over all others. We can deal with cases in which one conformation is so much preferred as to permit its consideration as if it were the unique rigid model of the molecule.

We are not operating within the slow exchange limit in which we would be able to observe lines belonging to



a: $R_1 = R_2 = H$
b: $R_1 = D$; $R_2 = H$
1



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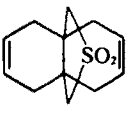

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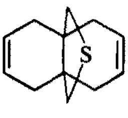

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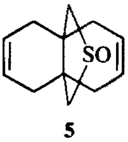

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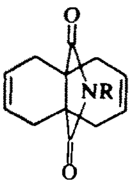

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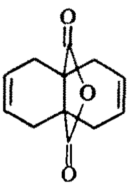
a: R = H
b: $R = CH_3$



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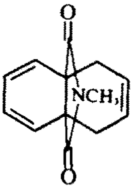

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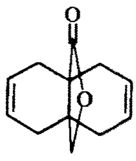

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†Propellanes—XXXII. A. Rüttimann and D. Ginsburg, *Helv. Chim. Acta* in press.

‡The PDIGM program was slightly modified such that a least squares fit for each particular proton shift *vs* concentration of lanthanide shift reagent could be obtained. The shift values along these fitted lines, each value corresponding to a specific concentration of lanthanide, were then correlated by the program to the experimental shifts. In addition, a slight modification permitted the program to consider different complexation sites.

several separate and distinct conformations. We are operating within the fast exchange limit. When we obtain a small absolute value of R (the value reflecting the correspondence of the experimental and calculated spectra), it is clear that although we have discovered the major conformation we cannot decide quantitatively as to the exact number and relative weights of other, minor, conformations which may be present.

Our method is therefore efficacious for qualitatively determining the preferred conformation without attempting to quantitatively determine populations in different conformations. One can judge fairly well the extent that a given conformation is preferred by the absolute value of R. But in so doing one should also concurrently consider other factors which may cause the value of R to rise, e.g. protons whose coordinates are difficult to define, those whose chemical shifts are difficult to determine, difficulty in exact definition of the site for complex-formation.

EXPERIMENTAL

The NMR spectra were measured on a Varian T-60 spectrometer. The sample was dissolved in dry $CDCl_3$ and to it were added subsequently at intervals measured quantities of solid sublimed $Eu(DPM)_3$. The NMR spectrum was measured after each such addition. The proton coordinates were usually determined by using Dreiding models and information from the literature regarding specific bond-lengths.

RESULTS AND DISCUSSION

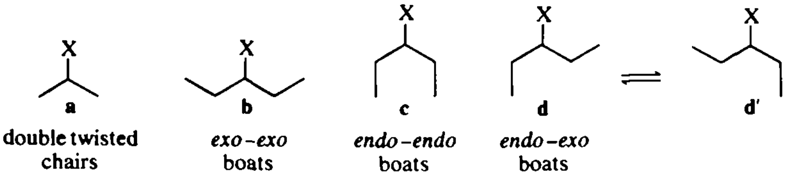
Compounds **1–4**. Table 1 lists the chemical shifts (in Hz) of protons in the molecules **1–4**. The spectrum of **1a**[2c] is a typical representative of this group. Common to them all is the pattern of allylic protons which appears as a degenerate system at δ 2·0–2·3 ppm.

Table 1.

Compound	Allylic H	Vinylic H	Hα-to Hetero atom
1a	125	335	224
1b	118	338	224
2	120	334	164
3	135	337	188
4	128	331	168

The effect on the chemical shifts of the α-protons by the hetero-atoms, which appears in the order $O > SO_2 > S \gg N$ may be attributed to changes in through-bond deshielding and the electric field effect and magnetic anisotropy of the relevant atoms or groups. As lanthanide shift reagent is added, degeneracy of the allylic system disappears and it spreads into an AA'BB'XX' system (X = vinylic protons).

The allylic protons (cf R_1 and R_2 in **1a**) appear as 4 broadened singlets, i.e. their fine-splitting by the vinylic protons is similar. The conformations considered as realistic for this group of compounds are **a–d**.



We have carried out calculations for **1–3** in terms of the conformations **a–d**. This was not done for **4** since it is, as expected, nearly inert to lanthanide shift reagent. For **3** two sets of calculations were conducted; in one the sulfur served as the origin (assuming complexation simultaneously to both oxygens), in the other, one of the oxygens was taken as the origin (assuming each oxygen can complex the reagent independently of the other). For reasons of symmetry the calculations were carried out for one quarter of the volume around the molecule concerned. Table 2 summarizes the results.

It may be concluded that **c** is the preferred conformation for **1** and for **2** but in view of the relatively high value of R in the latter case there must be additional relatively well-populated minor conformations present. In the case of **3** we learn not only that **c** is again preferred but that the shift reagent is complexed as shown in Fig. 1. It is presumed but not proven that **4** also exists mainly as **c**. We have also performed calculations for **3** in which we considered the O atom(s) as origin. The results obtained did not appear to have physical significance and were therefore disregarded and not listed in Table 2. The distance of the europium atom from the origin in **3c** appears rather high. We have been unable to find any other work in the literature with which this result may be compared.

There is great similarity (near-identity) between the disposition of the complex in **1** (Fig. 2) and **2**, perhaps owing to the similarity of the directions of the lone pair orbitals of oxygen and nitrogen and their size.

One might ask in view of the finding of a common

Table 2.

Compound	Origin (Atom)	Conformation	R %	d Å	φ	ρ	Remarks
1a	O	*a*					no minimum (= n.m.) R > 7%
	O	*b*					n.m. R > 12·8%
	O	*c*	1·67	2·4	72°	50°	
	O	*d*	4·58	5·0	5°	70°	
2	N	*a*					n.m. R > 14%
	N	*b*	15·9	2·3	66°	50°	
	N	*c*	7·1	2·3	72°	50°	
	N	*d*	12·43	5·2	0°	70°	
3	S	*a*					n.m. R > 10·5%
	S	*b*					n.m. R > 13%
	S	*c*	1·79	5·7	0°	80°	
	S	*d*	11·74	5·0	3°	90°	

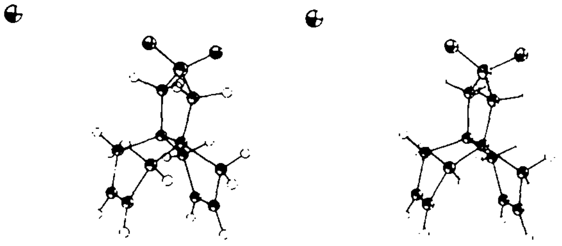


Fig. 1. Three-dimensional representation of sulfone 3 complexed to LSR (only Eu atom is shown).

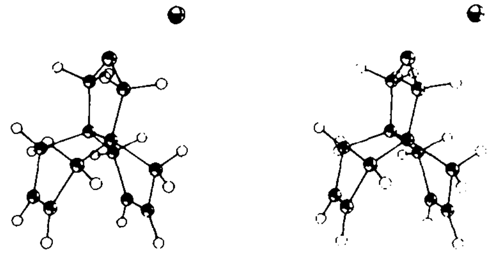
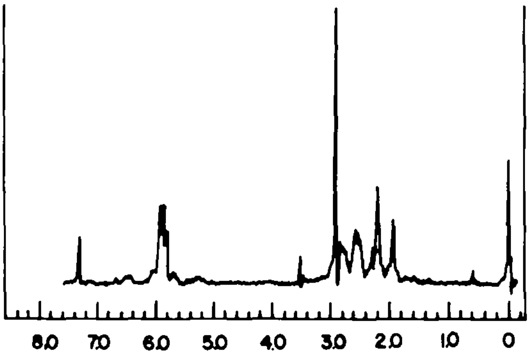


Fig. 2. Three-dimensional representation of ether **1a** complexed to LSR (only Eu atom is shown).

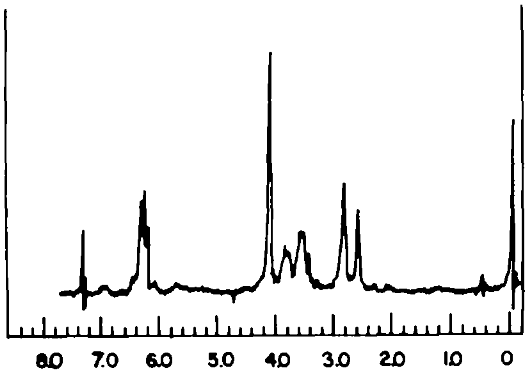
conformation for these molecules whether the shift reagent may not, due to steric or stereoelectronic reasons direct the conformational equilibrium towards c. An answer is obtained from a study of the extent of splitting of the vinylic protons in **1**. Were the lanthanide shift reagent responsible for displacing the equilibrium towards **c**, we would expect stepwise variation in the splitting of the vinylic protons by their allylic neighbors owing to the stepwise averaging in the dihedral angle between both sets of protons with the change in conformation. This point was checked in **1b**[2c] which has only one type of allylic proton. The unambiguous result was that there was no change in the extent of splitting of the vinylic protons. Therefore there was no difference between the preferred conformation of **1b** (and presumably in the other substrates in this group) from the outset to the end of the spectral measurements.

Compounds **6–8**. Figure 3 presents the NMR spectrum of **6b** which is typical for this group. A common feature is the presence from the start of an $A_2B_2X_2$ system for the allylic protons. This system does not average out as in the previous group owing to the anisotropic effect of the CO groups which causes a significantly different magnetic environment for the allylic protons *syn* and *anti* to the heterocyclic ring. The spectrum of **9** supports this conclusion. It contains elements in the heterocyclic ring common to both groups of substrates discussed herein, CH_2 as in **1–4** and CO as in **6–8**. In **9** the allylic protons whose nearer neighbor is a CO group are split to give an ABX system whilst those companions to the CH_2O group average out to affort a multiplet as exhibited by **1–4**.

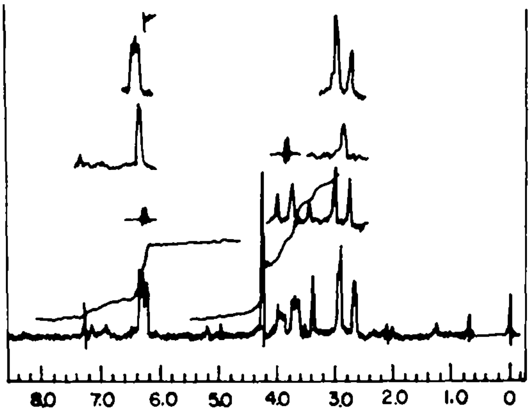
In the group **6–8** the pseudoequatorial allylic protons exhibit an additional splitting very different from that shown by the pseudoaxial one. We have considered seriously only conformations **b**, **c** and **d**, **a** being rejected because of the fact that the pseudoaxial and pseudoequatorial allylic protons maintain their identity (Fig. 3). Further, it appears after addition of lanthanide shift reagent that these two types of allylic protons maintained their relative positions with respect to the heterocyclic ring. (The pseudoequatorial protons were equally influenced and not split into two such sets upon addition of LSR). No calculations were carried out for **7** because the induced shifts were too small. We conducted calculations for both attachment of the LSR to the carbonyl oxygen or to the hetero-atom. Table 3 lists the pertinent results.



(a) NMR spectrum of **6b** in $CDCl_3$;



(b) LSR NMR spectrum of **6b** in $CDCl_3$;



(c) Decoupled LSR NMR spectrum of **6b** in $CDCl_3$.

Fig. 3.

We conclude from the data in Table 3 that the preferred conformation for **6a**, **6b** and **8** (and presumably **7**, by analogy) is **b**. Clearly, the LSR is complexed to the carbonyl oxygen (Fig. 4).

The X-ray structure of **6b** shows that its conformation in the solid state corresponds to **b**.[6]

Finally, we wish to report our results heretofore with respect to the sulfoxide **5**. This is of particular interest because *a priori* this is not a symmetrical molecule with respect to the plane of the heterocyclic ring. Its NMR spectrum, not surprisingly, exhibits two different allylic systems, degenerate and distinct.

Table 3.

Compound	Origin (atom)	Conformation	R %	d Å	ϕ	ρ	Remarks
6a	N	*b*					n.m. R > 70%
	N	*c*					n.m. R > 70%
	N	*d*					n.m. R > 17·7%
	O	*b*	1·75	3·3	70°	65°; 115°	
	O	*c*	5·96	3·1	80°	40°; 140°	
	O	*d*					shallow minimum at 3·2 Å; R = 15·8%
6b	N	*b*	25·72	2·5	10°	72°	
	N	*c*	22·67	2·3	50°	0°	
	N	*d*					n.m. R > 18·3%
	O	*b*	1·00	3·5	110°	45°; 135°	
	O	*c*	7·82	3·6	50°	30°	
	O	*d*					n.m. R = 17·0%
8			0·56	2·8	130°	54°; 126°	
	O	*b**	0·72	3·2	120°	50°; 130°	
	O	*c**	7·83	3·6	50°	30°	

*Conformation for cyclohexene ring only.

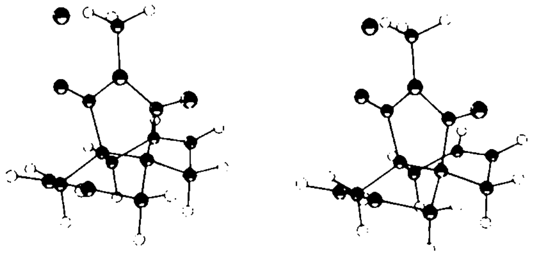
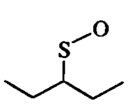


Fig. 4. Three-dimensional representation of methylimide **6b** complexed to LSR (only Eu atom is shown).

Upon addition of LSR, the former remains degenerate but the latter spreads out to an AA'BB'XX' system since the previous difference is exaggerated by the complexing of the LSR to the sulfoxide oxygen. But we note that the vinylic protons in *both* cyclohexene rings remain identical also after addition of the LSR. From the latter observation alone it may be concluded that the sulfoxide prefers conformation **f**. Our final results will be reported later.



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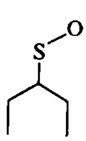

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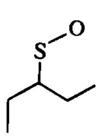

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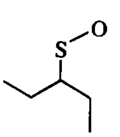

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From our results so far it is clear that the nature of the heterocyclic ring is of great importance in determining the preferred conformation of the molecule as a whole. Further work may cast sufficient light on the factors involved so as to enable prediction in as yet untested substrates.

Similar lanthanide shift studies using ^{13}C and $Pr(Fod)_3$ have been carried out on propellane-$Fe(CO)_3$ complexes and these will be reported separately.[7]

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