

## An Unusual Example of Stereoelectronic Control in the Ring Opening of 3,3-Disubstituted 1,2-Dichlorocyclopropenes

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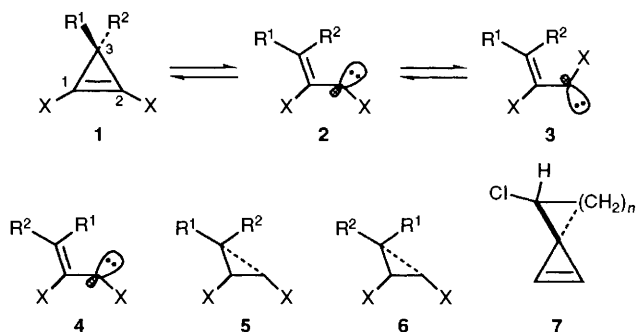
Quantitative SCF-MO calculations at the PM3 and *ab initio* level reveal that the origin of the stereoselective ring opening of 1,2-dichloro-3,3-disubstituted cyclopropenes (**1**, R<sup>2</sup> = CH<sub>2</sub>Cl, CH<sub>2</sub>OMe or CH<sub>2</sub>Ph) to give vinylcarbenes **2** *via* transition state **5** arises from stereoelectronic control, in contrast to that of cyclopropenes having bulky non-polar substituents such as R<sup>2</sup> = Pri which favours a less hindered transition state **6**.

There is considerable current interest in the diversity of thermal ring opening reactions of cyclopropenes **1**, the products including alkynes,<sup>1</sup> allenes<sup>2</sup> and species which can be represented as vinylcarbenes **2**.<sup>3</sup> Certain substituents lower the temperature required for ring opening quite markedly.<sup>4</sup> In particular, 1,2-dichloro-3,3-dimethylcyclopropene (**1**, R<sup>1</sup> = R<sup>2</sup> = Me, X = Cl) has been shown to ring open at 0–20 °C, apparently *via* transition states (**5** or **6**) corresponding to electrocyclic ring opening of *e.g.* and C<sub>2–3</sub> σ-bond and concomitant rotation about the C<sub>1–3</sub> bond. The products are singlet carbene equivalents (**2–4**) which are readily trapped in intermolecular processes.

When the two substituents on C<sub>3</sub> are different, the formation of carbenes isomeric about the double bond (**2** or **4**) is possible. Thus for (**1**, X = Cl, R<sup>1</sup> = Me, R<sup>2</sup> = CH<sub>2</sub>Cl or

CH<sub>2</sub>OMe) in the presence of an added alkene, only isomer **2** is trapped, whereas with R<sup>1</sup> = Me; R<sup>2</sup> = CH<sub>2</sub>Ph or R<sup>2</sup> = Et, increasingly lower selectivities of **2**:**4** ≈ 5:1, and **2**:**4** ≈ 1:1 respectively are observed. The opposite stereocontrol is shown by alkyl cyclopropenes (**1**, X = Br, R<sup>1</sup> = H; R<sup>2</sup> = Me or R<sup>2</sup> = Pri)<sup>5</sup> for which only carbenes **4** are inferred from alkene trapping. We present here a quantitative analysis of this stereospecificity in terms of a novel form of stereoelectronic and entropic control, together with predictions for hitherto untested substituents.

The calculated activation enthalpies and selected entropies and free energies<sup>†</sup> for a range of substituents (Table 1) reveal the following trends. The substitution of X = Cl for X = H markedly lowers the activation enthalpy, in agreement with experimental observation,<sup>4</sup> which we attribute to resonance stabilisation of the halogenocarbene. This effect also enables us to justify the use of closed shell single determinantal wavefunctions in studying these reactions, since the importance of biradical character is reduced<sup>6</sup> in such singlet

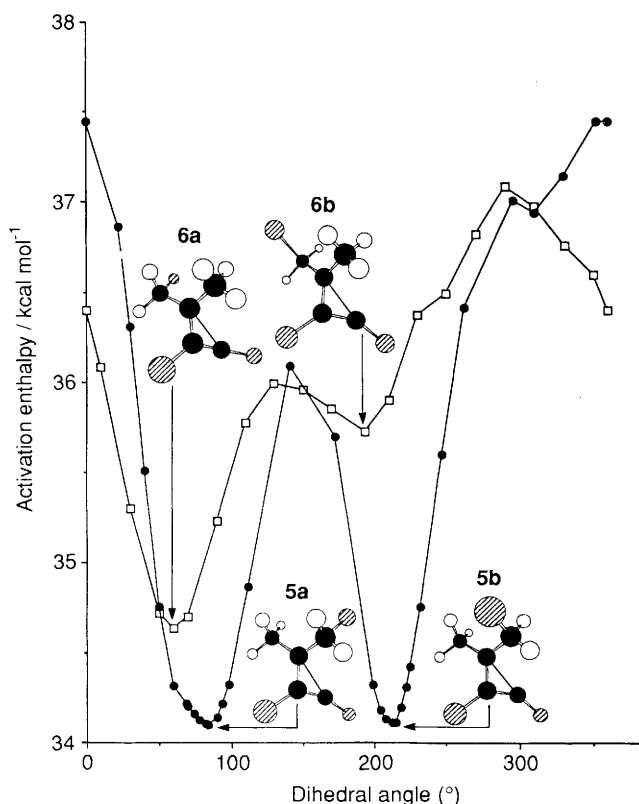


<sup>†</sup> Geometries were optimised at the PM3<sup>10</sup> level using the MOPAC program (versions 5.2 and 6.0). Transition states were located using the eigenvector following method<sup>11</sup> and stationary points so located had one negative eigenvalue in the Hessian matrix as required of a transition state, with the correct displacement coordinates. Molecular entropies were calculated from the normal vibrational frequencies obtained from the mass-weighted Hessian matrix.

**Table 1** Calculated enthalpies (kcal mol<sup>-1</sup>) and free energies (kcal mol<sup>-1</sup>) on the potential surface for ring opening of **1**

XR <sup>1</sup>	R <sup>2</sup>	<b>1</b> ΔH	<b>5</b> ΔH <sup>‡</sup> (ΔG <sup>‡</sup> )	<b>6</b> ΔH <sup>‡</sup> (ΔG <sup>‡</sup> )	<b>2</b> ΔH	<b>4</b> ΔH
H H	Me	60.18	50.77	48.07	101.71	101.36
F H	Me	-17.01	31.85	29.29	-15.18	-15.71
Cl H	Me	48.458	38.26 (37.93)	36.00 (35.47)	66.62	66.69
Br H	Me	91.879	33.49 (33.10)	31.88 (31.32)	98.40	98.96
I H	Me	119.31	29.73	29.52	129.90	129.53
Cl H	Pr <sup>i</sup>	39.22	37.41 (36.98)	35.45 (34.63)	56.54	56.53
Cl Me	Et	36.45	34.97 (34.65)	35.07 (35.13)	51.96	52.77
Cl Me	CH <sub>2</sub> OMe	7.51	34.39 (32.97) <sup>a</sup>	35.06 (34.99) <sup>a</sup>	22.85	23.04
Cl Me	CH <sub>2</sub> F	0.88	35.52 <sup>b</sup>	36.07 <sup>b</sup>	17.43	17.88
H Me	CH <sub>2</sub> Cl	49.87	46.64 <sup>a</sup>	48.47 <sup>a</sup>	88.70	89.22
Cl H	CH <sub>2</sub> Cl	46.27	37.06 (35.97) <sup>a</sup>	35.92 (34.57) <sup>b</sup>	64.37	64.75
Cl Me	CH <sub>2</sub> Cl	38.99	34.10 (32.77) <sup>b</sup>	35.72 (35.12) <sup>b</sup>	54.72	55.82
Cl Me	CH <sub>2</sub> Cl	-1562.9329 <sup>c</sup>	34.10 (33.68) <sup>a</sup>	34.63 (33.50) <sup>a</sup>		
Cl Me	CH <sub>2</sub> Cl		21.40 <sup>b</sup>	25.60 <sup>b</sup>		
Cl 7(n=1) <sup>d</sup>		78.58	42.59	42.61	103.63	103.53
Cl 7(n=2) <sup>d</sup>		56.06	39.97	40.44	77.57	77.64
Cl 7(n=3) <sup>d</sup>		35.35	35.70 (35.27)	36.52 (35.15)	52.52	53.19
Cl Me	Ph	75.52	34.46	34.71	89.52	92.35
Cl Me	CH <sub>2</sub> Ph	71.17	33.18 (33.90) <sup>b</sup>	34.05 (35.07) <sup>a</sup>	85.23	85.71
Cl Me	CH <sub>2</sub> SiH <sub>3</sub>	51.18	31.14 <sup>a</sup>	31.29 <sup>a</sup>	62.99	62.85
Cl H	SiH <sub>3</sub>	62.17	37.67	37.14	81.07	80.88
Cl H	OMe	30.37	25.07	19.64	36.58	33.25
Cl H	Cl	50.06	40.25	38.27	71.45	71.14

<sup>a</sup> Conformation **5a**: **6a** <sup>b</sup> Conformation **5b**: **6b**. <sup>c</sup> *Ab initio* energy at the 3-21G basis set level, in Hartree. <sup>d</sup> R<sup>1</sup> = -CHCl-, R<sup>2</sup> = -(CH<sub>2</sub>)<sub>n</sub>-.



**Fig. 1** Calculated PM3 transition state activation enthalpy as a function of the dihedral angle subtended by the atoms Cl-C-C(3)-C(2) for (●) transition state (**5**, R<sup>1</sup> = Me, R<sup>2</sup> = CH<sub>2</sub>Cl) and (□) transition state (**6**, R<sup>1</sup> = Me, R<sup>2</sup> = CH<sub>2</sub>Cl). Shown as inserts are the calculated PM3 transition state geometries.

carbenes. In absolute terms, the PM3 barriers are ≈ 10–15 kcal mol<sup>-1</sup> (1 cal = 4.184 J) higher than inferred from experiment and calculated at the *ab initio* level (Table 1).<sup>6</sup> The

difference in the energies of **5** and **6** is the more significant, since a greater cancellation of errors may be expected. Where R<sup>1</sup> and R<sup>2</sup> are both non-polar alkyl groups or R<sup>1</sup> = H, **6** is enthalpically favoured on steric grounds, in agreement with experiment. Where R<sup>2</sup> bears a polar C-Y bond (Y = F, Cl, OMe) this preference is reversed in favour of **5**, at both the PM3 and (for R<sup>2</sup> = CH<sub>2</sub>Cl) at the 3-21G *ab initio* level, but (we predict) is not dependent on the nature of the substituent X (Table 1).<sup>7</sup>

The small calculated differences in the dipole moments of **5** and **6** indicate that differential solvation in solvents of moderate polarity (ε ≈ 5–15) is not likely to be the cause of the stereoselectivity.<sup>8</sup> Instead, a detailed analysis reveals the effect to be largely stereoelectronic. For each transition state, two low energy conformers are possible (Fig. 1), in which the C-Y σ-bond can be described as *approximately* orthogonal (**5a**, **6a**) or anti-periplanar (**5b**, **6b**) with respect to the C<sub>2-3</sub> σ-bond. We note that in the three-membered ring, the bent C<sub>2-3</sub> σ-bond does not necessarily correspond to the axis defined by the two carbon atoms! For the case of R<sup>1</sup> = Me, R<sup>2</sup> = CH<sub>2</sub>Cl, the LUMO + 2 corresponds to the C-Cl σ\* orbital (Fig. 2), whilst the HOMO clearly corresponds to the leaving C-C bond. Interaction between these two orbitals stabilises the HOMO significantly more in the anti-periplanar (**5b**, -8.185, **6b**, -8.005 eV) than in the orthogonal orientation (**5a**, -7.859, **6a**, -7.664 eV) and the enthalpy difference between **5b** and **6b** is at a maximum because the transition state geometry allows the C-Cl and the C<sub>2-3</sub> σ-bonds to be almost parallel in **5b**, whereas this is less true of **6b** (Fig. 2). With R<sup>1</sup> = Me, R<sup>2</sup> = CH<sub>2</sub>Cl, **6a** actually resides on a different potential energy surface in which the C(1)-C(2)-X angle is essentially linear, and which may be an artefact of the PM3 procedure. This is not the case at the PM3 level with *e.g.* R<sup>1</sup> = Me, R<sup>2</sup> = CH<sub>2</sub>F, or at the *ab initio* level with R<sup>2</sup> = CH<sub>2</sub>Cl, for which **5b** is clearly the preferred geometry. The two-electron stereoelectronic stabilisation we are suggesting for **5** contrasts with the *destabilising* four-electron interaction inferred as responsible for stereoelectronic control of the electrocyclic ring opening of 3-methoxy-3-*tert*-butylcyclobutene.<sup>9</sup> Our calculations do indicate that analogous effect favouring transition state **6** may be expected for the hitherto unstudied system (**1**, R<sup>1</sup> = H, R<sup>2</sup> = OMe, Table 1).

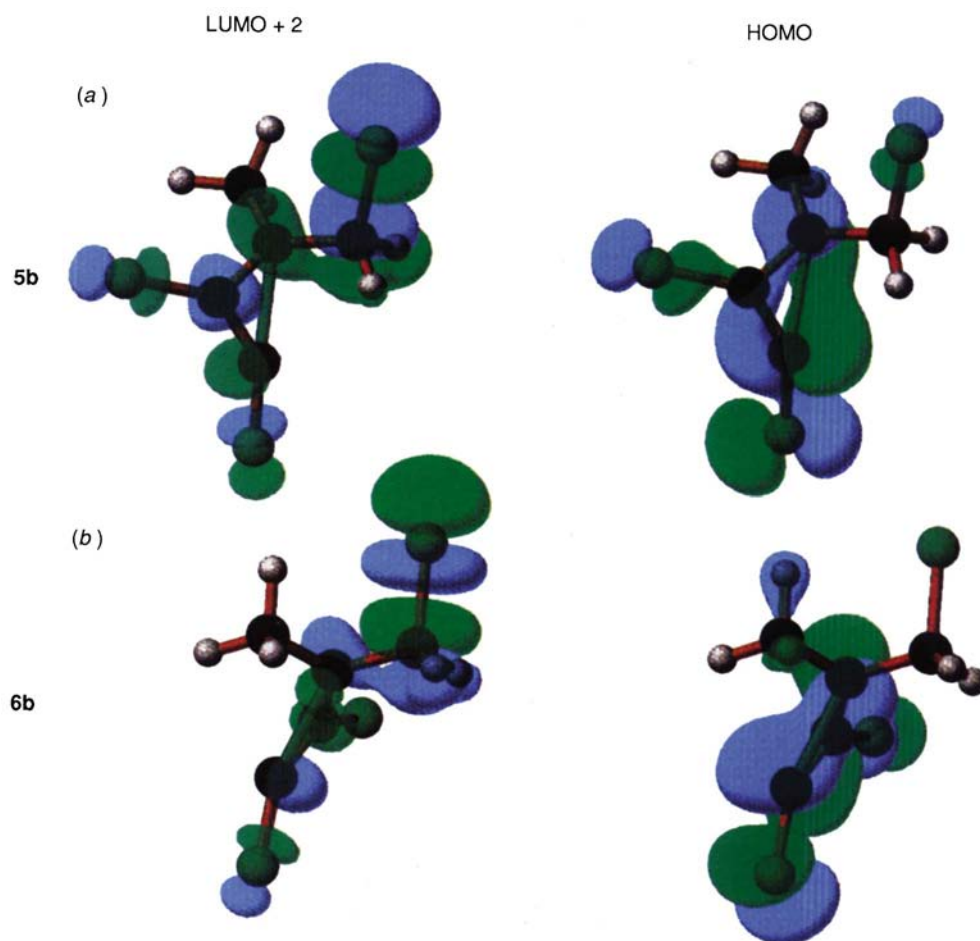


Fig 2 Calculated PM3 HOMO and LUMO + 2 orbitals for (a) (**5b**,  $R^1 = \text{Me}$ ,  $R^2 = \text{CH}_2\text{Cl}$ ) and (b) (**6b**,  $R^1 = \text{Me}$ ,  $R^2 = \text{CH}_2\text{Cl}$ ), showing a better parallel orbital alignment for **5** than for **6**.

Stereoelectronic orientation of *e.g.* the C–Y bond might be expected to influence the entropy contribution from the degrees of freedom associated with the C–C–Y bond. The calculated entropies<sup>‡</sup> were used to evaluate free energies of activation, and these reveal that a small increase in favour of **6** for bulky groups, and a small opposite effect in favour of **5a** occurs with *e.g.*  $R^2 = \text{CH}_2\text{Cl}$  (Table 1). Taken overall, these results suggest several interesting systems for future study. The system **1**,  $R^1 = \text{H}$ ,  $R^2 = \text{CH}_2\text{Cl}$  sets up the steric and stereoelectronic effects in opposition; we predict the winner (Table 1) to be steric control *via* **6**. Study of the spirocyclopropenes **7** would allow precise control of the stereoelectronic orientation of the C–Y bond *via* changes in ring size, and furthermore eliminate the rotational degree of freedom about the C–C–Y bond which influences the entropy. Our calculations indicate that for Y = Cl, only with  $n = 3$  is there predicted a small enthalpic preference for transition state **5**, which however vanishes when entropy is included. This implies that the **5**:**6** ratio for such a system may be more temperature dependent than was the case with the reactions of **1**. We also predict that substituents that do not give rise to an appropriately aligned low lying  $\sigma^*$  orbital (*e.g.*  $R^2 = \text{CH}_2\text{SiH}_3$ ) and groups such as  $R^2 = \text{Cl}$  or OMe which similarly cannot stabilise the C–C  $\sigma$ -bond will both favour **6**. Experiments to verify our predictions are under way.

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## References

- 1 R. Walsh, E. Wolf, S. Untiedt and A. de Meijere, *J. Chem. Soc., Chem. Commun.*, 1992, 421, 422.
- 2 W. E. Billups and R. E. Bachman, *Tetrahedron Lett.*, 1992, **33**, 1825.
- 3 J. R. Al Dulayymi and M. S. Baird, *Tetrahedron*, 1989, **45**, 7601; M. S. Baird and O. Stober, unpublished results.
- 4 M. S. Baird, S. R. Buxton and J. S. Whitley, *Tetrahedron Lett.*, 1984, **25**, 1509; M. S. Baird and H. H. Hussain, *Tetrahedron*, 1989, **45**, 6221.
- 5 J. R. Al Dulayymi, M. S. Baird and H. L. Fitton, *Tetrahedron Lett.*, 1992, 4803.
- 6 M. Yoshimine, J. Pakansky and N. Honjou, *J. Am. Chem. Soc.*, 1989, **111**, 2785, 4198.
- 7 For a similar stereoelectronic interpretation of  $\pi$ -bond selectivity, see B. Halton, R. Boese and H. S. Rzepa, *J. Chem. Soc., Perkin Trans. 2*, 1992, 447 and for  $\sigma$ -bond selectivity, see R. A. Batey, P. Grice, J. D. Harling, W. B. Motherwell and H. S. Rzepa, *J. Chem. Soc., Chem. Commun.*, 1992, 942.
- 8 M. M. Karelson, T. Tamm, A. R. Katritzky, S. J. Cato and M. C. Zerner, *Tetrahedron Comput. Method.*, 1989, **2**, 295; H. S. Rzepa, M. Yi, M. Karelson and M. C. Zerner, *J. Chem. Soc., Perkin Trans. 2*, 1991, 636.
- 9 K. N. Houk, D. C. Spellmeyer, C. W. Jefford, C. G. Rimbault, Y. Wang and R. D. Miller, *J. Org. Chem.*, 1988, **53**, 2125.
- 10 J. J. P. Stewart, *J. Comput. Chem.*, 1989, **10**, 209, 221; J. J. P. Stewart, *J. Comp. Aided. Mol. Design*, 1990, **4**, 1.
- 11 J. Baker, *J. Comput. Chem.*, 1986, **7**, 385; M. Lehd and F. Jensen, *J. Org. Chem.*, 1990, **55**, 1034; J. Baker, F. Jensen, H. S. Rzepa and A. Stebbings, *Quantum Chemistry Program Exchange Bulletin*, 1990, **10**, 76.