π-Mediated rearrangements and 1,2-H shifts of indanylcarbenes

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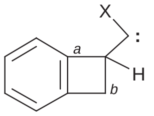
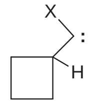
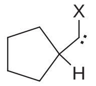
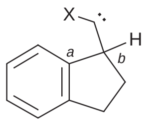
Absolute rate constants determined for 1,2-C and 1,2-H migrations of cyclobutyl-, cyclopentyl-, benzocyclobutenyl- and benzocyclopentenyl-(chloro)- or -(acetoxy)-carbenes reveal that 'phenyl' carbon migrations are preferred to alternative 1,2-C shifts due to π-electronic effects.

The 1,2-C migration of 'phenyl' carbon *a* is strongly preferred to that of 'benzyl' carbon *b* in benzocyclobutenylcarbenes **1-Cl**, **1-F** and **1-OAc**, whilst the 1,2-H shift is virtually non-competitive.[1] The 1,2-C shift specificity is attributable to mediation by the phenyl π-system.[1] Given the somewhat unusual nature of cyclobutylcarbenes,[2] such as **2-Cl**[3] and **2-OAc**,[4] where relief of strain may drive the 1,2-C shift ring expansion, we now extend our studies to cyclopentylcarbenes **3-Cl** and **3-OAc**, as well as their benzo derivatives, the indanylcarbenes **4-Cl** and **4-OAc**. The results imply that, despite dominant reassertion of the 1,2-H shift with carbenes **3-X** and **4-X**, π-assisted 1,2-C_a migrations remain favored over unassisted C_b shifts.


1-X


2-X


3-X

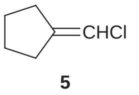

4-X

X = Cl, OAc, or F (for **1**)

All carbenes were generated from appropriate diazirine precursors. 3-Chloro-3-cyclopentyldiazirine (λ_{max} 348, 364 nm, pentane) was prepared in 35% yield by NaOCl oxidation[5] of cyclopentanecarboximidamide·HCl,[6] whereas 3-acetoxy-3-cyclopentyldiazirine (13%, λ_{max} 342, 354 nm, pentane) was obtained from a 'modified' Graham oxidation (LiOAc, NaOCl)[4] of the same amidine.† For the indanyl precursors, indan-1-one was converted (40%) to 1-cyanoindane[7] with tosylmethyl isocyanide and NaOEt in DME. The cyanoindane gave 58% of indane-1-carboximidamide·HCl upon reaction with $MeClAlNH_2$ (toluene, 80 °C, 30 h),[8] and the amidine was oxidized to 3-chloro-3-(indan-1-yl)diazirine (30%, λ_{max} 330, 346, 360 nm, pentane) with NaOCl,[5] or to the analogous acetoxydiazirine (9%, 338, 352 nm, pentane) with LiOAc/NaOCl.[4]† All diazirines were purified by chromatography on silica gel and characterized by NMR and UV spectroscopy.

Carbenes **3-X** and **4-X** were generated by photolysis (λ > 320 nm, 25 °C) and by thermolysis (78 °C) of pentane solutions of the diazirines (A = 0.5–0.7 at λ_{max}). Products were identified by GC-MS, and confirmed by comparisons with independently synthesized samples, or were isolated and characterized by NMR and GC-MS. All new products gave acceptable elemental analyses or high resolution MS molecular ions. All major products (> 5%) were characterized.

From **3-Cl**, we obtained only 1,2-H shift product **5**, which was synthesized from cyclopentanone and Ph_3P=CHCl. Carbene **3-OAc** gave enol acetate **6** by 1,2-H shift, and dione **7** by 1,2-Ac migration[4,9] in ratios of 1.17 : 1 (*hν*) or 1.23 : 1 (78 °C); no 1,2-C shift product was observed. Authentic **6** was readily obtained by reaction of cyclopentanecarbaldehyde with Ac_2O,[10] whilst **7** was prepared from the same starting material *via* conversion to *E*/*Z*-1-cyclopentylpropene with Ph_3P=CHMe, followed by oxidation with $KMnO_4$.[11]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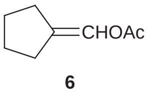
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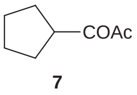
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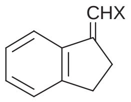
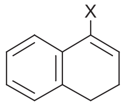
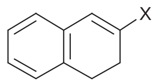
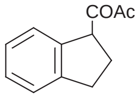
Indan-1-yl(chloro)carbene (**4-Cl**) produced H-shift products (*E*/*Z*)-**8-Cl**, as well as the isomeric 1,2-C shift products 1-chloroindene (**9-Cl**, *via* C_a migration) and 2-chloroindene (**10-Cl**, *via* C_b migration). The GC product distribution (**8-Cl** : **9-Cl** : **10-Cl**) was 8.2 : 1.0 : 0.03 (*hν*) or 10.0 : 1.0 : 0.03 (78 °C). Authentic chloroindenes were prepared by reactions of α-tetralone (for **9-Cl**) or β-tetralone (for **10-Cl**) with PCl_5 in benzene.[12] Alkenes **8-Cl** (*E*/*Z* ~ 5) were synthesized in 60% yield by NaOH-induced elimination of HCl from 1-dichloromethylindane, itself prepared by reaction of photogenerated **4-Cl** with HCl in pentane.


8-X


9-X


10-X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From acetoxyindanylcarbene, **4-OAc**, we obtained H-shift products (*Z*/*E*)-**8-OAc**, C-shift products **9-OAc** (*via* C_a migration) and **10-OAc** (*via* C_b migration), and the acetyl migration product, dione **11**. The **8-OAc** : **9-OAc** : **10-OAc**: **11** product distributions were 9.0 : 1.0 : 0.29 : 5.3 (*hν*) and 10.3 : 1.0 : 0.24 : 5.2 (78 °C). Authentic samples of **8-OAc**, **9-OAc** and **10-OAc** were synthesized by reactions of indane-1-carbaldehyde, α-tetralone or β-tetralone, respectively, with Ac_2O;[10] whilst dione **11** was identified by its GC-MS and associated cracking pattern.

Absolute rate constants (reproducibility ~ ±15%) for the carbenic rearrangements were determined at 25 °C by laser flash photolysis (LFP)[9] of pentane solutions of the appropriate diazirines (A_{max} = 0.5–0.7 at λ_{max}) at 351 nm, using the pyridine ylide method.[4,9,13] Growth of the carbene–pyridine ylide was monitored at 390 nm. Details of this methodology, as applied to the carbenic rearrangements, have been described.[4,9]

The absolute rate constants determined for the aggregate rearrangements of carbenes **3-Cl**, **3-OAc**, **4-Cl** and **4-OAc** were (where appropriate) partitioned into k_H, k_C and k_{Ac}, in accord with the product distributions given above. In the case of **4-Cl**, the product distribution is likely biased by rearrangement directly from the excited diazirine,[1,3a,14] so that we partitioned the aggregate rate constant using the 78 °C thermolysis product distribution. Excited state diazirine rearrangements are not expected in the acetoxycarbene series.[4,15] The partitioned rate constants appear in Table 1, together with related data for carbenes **1-Cl** and **1-OAc**,[1] **2-Cl**[3] and **2-OAc**,[4] Me_2CHCCl[16] and $Me_2CHCOAc$.[4] The **2-Cl** rate constants are corrected for excited diazirine contributions,[3] whereas the 78 °C thermal product distribution is given for **1-Cl**.[1]

The most immediate observation from Table 1 is the dominance of the 1,2-H shift in the chemistry of the five-membered ring carbenes. In the absence of strain relief to drive the ring expansion, as in cyclobutylcarbenes **2-OAc** and **2-Cl**,

Table 1 Absolute rate constants of carbenic rearrangements

	Rate constants/s^{-1}			
Carbene	1,2-H	1,2-C_a	1,2-C_b	1,2-Ac
Me_2CHCCl[a]	$>10^8$			
$Me_2CHCOAc$[b]	4.0×10^6			4.0×10^6
2-Cl[c]	1.2×10^7	5.6×10^7	[d]	
2-OAc[b]	1.3×10^4	3.2×10^4	[d]	4.0×10^5
3-Cl[e]	2.2×10^7			
3-OAc[e]	2.9×10^6			2.4×10^6
1-Cl[f,g]	(1.0)	(92)	(7.0)	
1-OAc[f]		8.5×10^6	$< 8.5 \times 10^4$	
4-Cl[e]	1.4×10^7	1.5×10^6	4.5×10^4	
4-OAc[e]	1.4×10^5	1.6×10^4	4.7×10^3	8.5×10^4

[a] Ref. 16. [b] Ref. 4. [c] Ref. 3*a*. [d] $C_b = C_a$. [e] This work. [f] Ref. 1. [g] Only the 78 °C product distribution is available; cf. ref. 1.

where k_C exceeds k_H by factors of 2.5–4.7,‡ the 1,2-H shift is preferred. In cyclopentylcarbenes[17] **3-Cl** and **3-OAc**, it is preferred by a factor of at least 50.§

More to the point, the π-mediation effects, detected in the benzocyclobutenylcarbenes **1-X**,[1] also appear to operate with benzocyclopentenylcarbenes **4-X**, where phenyl carbon (C_a) migrations exceed C_b shifts by factors of 33 (X = Cl) or 3.4 (X = OAc). Importantly, the C_a migrations are *accelerated* by the benzo units whatever the outcome of the k_H *vs.* k_C competition; comparisons of **1-OAc** to **2-OAc**, **4-Cl** to **3-Cl** and **4-OAc** to **3-OAc** reveal significant $k_C(a)$ enhancements.

Other themes may be discerned in Table 1. Anticipated decreases in both k_H and k_C are observed as consequences of replacing carbenic Cl by OAc 'spectator' substituents.[4] These decreases are common to isopropyl-, cycloalkyl- and benzocycloalkenyl-carbenes. Additionally, k_{Ac} is slowed ⩾28 times in the benzocycloalkenylcarbenes **1-OAc** and **4-OAc**, relative to Pr^iCOAc or **3-OAc**, which may well reflect stabilization of the former carbenes' vacant p orbitals by the same homo-π donation[1] that is central to the π-mediation of their C_a migrations. (The ten-fold decrease in k_{Ac} of **2-OAc**, relative to Pr^iCOAc, is attributable to enhanced electron donation by the cyclobutyl moiety.[3c,4])

We conclude that π-mediation of carbenic 1,2-C migrations is not an isolated occurrence, but may occur generally in appropriate systems.

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Notes and references

† Both chloro and acetoxy diazirines are produced, but are separable by silica chromatography with 1:2 CH_2Cl_2–pentane.

‡ Additionally, 1,2-H migration is disfavored in cyclobutylcarbenes due to the unfavorable imposition of δ+ on the cyclobutyl carbon during hydride migration (ref. 4).

§ The experimental results are mirrored by calculations at the B3LYP/6-311 + G(d,p)//MP2/6-31G(d) level with ZPE corrections (GAUSIAN 94, Revision B.1) which give E_a for the 1,2-H and 1,2-C shifts of **2-Cl** as 6.0 and 5.6 kcal mol^{-1}, modestly favoring 1,2-C migration, as compared to E_a = 1.9 and 8.1 kcal mol^{-1} for the analogous reactions of **3-Cl**, where 1,2-H migration is strongly preferred.

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