CHEMISTRY LETTERS, pp. 697-700, 1981.

BARRIERS TO ROTATION AND INVERSION IN 1,1'-BIPIPERIDINES

Keiichiro OGAWA, Yoshito TAKEUCHI, Hiroshi SUZUKI, and
Yujiro NOMURA
Department of Chemistry, College of General Education,
The University of Tokyo, Komaba, Meguro-ku, Tokyo 153

A ^{13}C dynamic NMR of meso-1,1'-bi(2-methylpiperidine)s revealed that the barrier to the single-passing rotation about the N-N bond was at least 74.1 kJ mol^{-1}, which was considerably higher than the barrier to the passing inversion of the nitrogen atom.

The conformational analysis of hydrazines has remained as a challenging problem for the last three decades chiefly because of its dichotomic nature. Usually one distinct rate process was observed by ^{1}H dynamic NMR experiments of acyclic tetra-alkylhydrazines, the free energy of which was variable depending on the structure.[1-3] A low energy barrier of about 30 kJ mol^{-1} was assigned to the non-passing inversion of the nitrogen atom, an inversion which does not involve eclipsing of substituents in the transition state, while a high energy barrier of about 45 kJ mol^{-1} was assigned to the rotation about the N-N bond. But the passing inversion of nitrogen atom, an inversion which involves eclipsing of substituents, as well as the single-passing rotation about the N-N bond, a rotation which involves eclipsing of only one pair of substituents in the transition state, can account for the high energy barrier.[4,5]

Here we wish to report the first successful differentiation between the two alternatives based on the selective perturbation of the transition state of one of the two pathways.

Our choice was a ^{13}C dynamic NMR of meso-1,1'-bi(2-methylpiperidine)(1)[6] and meso-1,1'-bi(cis-2,4-dimethylpiperidine)(2).[7] The 2-methyl groups of 1 and 2 introduce chiral centers into the molecule, which are essential for carbon atoms of two piperidine rings to be non-equivalent when the rate process slows down. The 4-methyl groups of 2, a key to the intended selective perturbation, cause a large steric interaction with 2-methyls when ring inversion takes place.

All the peaks in the ^{13}C NMR spectra of 1 and 2 split into two peaks of equal intensity as the temperature was lowered. The free energies of activation to the rate processes were calculated from the exchange rates at the coalescence temperatures (see Table for results).[8)]

It is established that in the most stable conformation of 1,1'-bipiperidine the unshared electron pairs of the nitrogen atoms are gauche to each other (the torsion angle ≃ 90°) with the N-N bond equatorial to both the piperidine rings.[9,10)] Hence, the most stable conformations of 1 and 2 are certainly the enantiomeric gauche conformations Gee+ and Gee-, in which all the methyl groups are equatorial, as shown in Scheme. The observation that all the signals in 1 and 2 split into two peaks of equal intensity on cooling suggests the freezing of the interconversion Gee- ⇄ Gee+ at the observed temperature on the NMR time scale. The barrier estimated for this exchange process corresponds to the lowest barrier one among several possible paths for the interconversion between Gee- and Gee+. This path is most likely to involve the intermediates with the lowest energy in which the N-N bond is equatorial to both the piperidine rings. The double-passing rotation path (path R1 in Scheme), a path through the fully eclipsed conformation, cannot be the lowest barrier path, because this conformation should have higher energy than the eclipsed conformations involved in the course of the single-passing rotation path, path R2 (Gee- ⇄ Tee ⇄ Gee+), where Tee is the trans conformation in which all the methyl groups are equatorial. Thus, the lowest barrier path must be a path through a trans conformation. Tee is the lowest one of trans

Table Spectral Data and Free Energy of Activation($\Delta G^{\ddagger}_{c}$) estimated at the Coalescence Temperature(T_c).

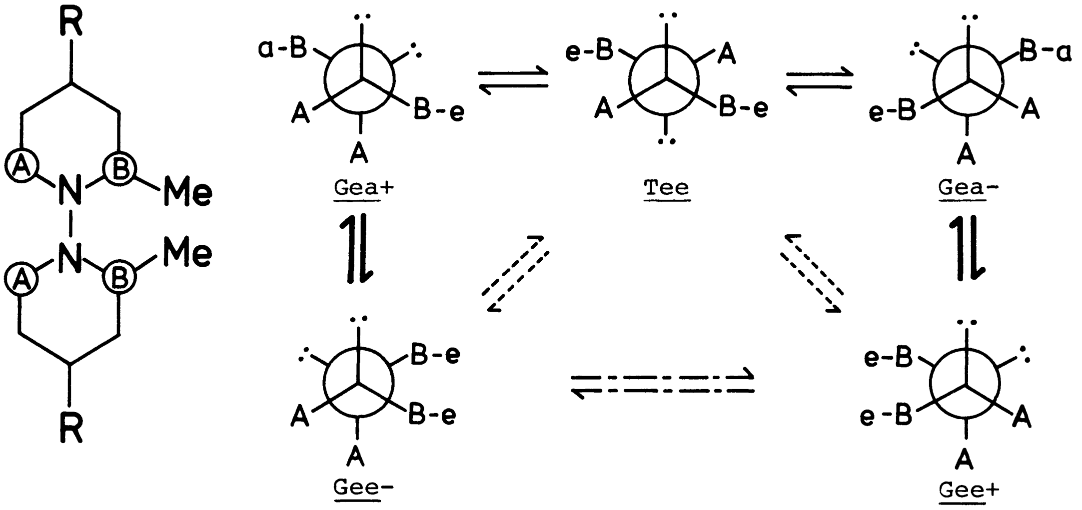
Compd.	Solvent	Position	$\Delta\nu$/Hz	T_c/°C	$\Delta G^{\ddagger}_{c}$/kJ mol^{-1}
1	THF-d_8/CS_2	2,2'	40.0	-18	52.7
	=5/6	6,6'	294.9	—[a)]	
		3,3'	3.9	-40	52.3
		5,5'	18.6	-25	52.7
		4,4'	11.2	-29	52.7
		2-Me, 2'-Me	75.2	-10	53.1
2	Diglyme-d_{14}	2,2'	(46.4)[b)]	—[a)]	
		6,6'	(307.1)	—[a)]	
		3,3'	9.3	62	74.1
		5,5'	20.5	72	74.1
		4,4'	19.5	71	74.1
		2-Me, 2'-Me	(8.8)[b)]	—[a)]	
		4-Me, 4'-Me	(40.0)[b)]	—[a)]	

a) T_c was not determined. b) Value based on a preliminary assignment.

conformations. One of paths through Tee is path R2 and another one is path I (Gee- ⇄ Gea+ ⇄ Tee ⇄ Gea- ⇄ Gee+), which involves passing and non-passing inversions of nitrogen atoms and ring inversions. Gea+ and Gea-, in which the methyl groups on one piperidine ring are equatorial and those on another ring are axial, are most likely the next stable ones of gauche conformations and they must have lower energy than Tee in case of 1.11) Therefore, the lowest barrier path for the interconversion between Gee- and Gee+ should be one of two paths, R2 and I.

In path R2 the transition state energy of 2 should be nearly equal to that of 1. In path I, as intermediates Gea+ and Gea- of 2 are destabilized by 1,3-diaxial interaction of the methyl groups compared with the corresponding conformations of 1, the transition state energy of 2 is expected to be higher than 1 to the extent of the non-bonded interaction. The magnitude of the 1,3-diaxial interaction of the methyl groups in cis-2,4-dimethylpiperidine is expected to be comparable with that in cis-1,3-dimethylcyclohexane, which was estimated at about 15.5 kJ $\mathrm{mol^{-1}}$.12,13)

Scheme



1 : R = H
2 : R = Me

Path R1 : Gee- ⇄ Gee+
path R2 : Gee- ⇄ Tee ⇄ Gee+
Path I : Gee- ⇄ Gea+ ⇄ Tee ⇄ Gea- ⇄ Gee+

Legend:
➞ , a non-passing inversion of the nitrogen atom coupled with a ring inversion; ⟶ , a passing inversion of the nitrogen atom coupled with a ring inversion; ----⇀, a single-passing rotation about the N-N bond; -·-⇀ , a double-passing rotation about the N-N bond. Symbols e and a represent equatorial and axial methyls, respectively. Symbols + and - represent the sign of the torsion angle with respect to the lone pairs.

Here the activation free energies observed for 1 and 2 are represented by $\Delta G^{\ddagger}_{obs}(1)$ and $\Delta G^{\ddagger}_{obs}(2)$, respectively, and the barrier to the single-passing rotation about the N-N bond for 1 as well as 2 is represented by $\Delta G^{\ddagger}_{rot}$. If $\Delta G^{\ddagger}_{obs}(1) \simeq \Delta G^{\ddagger}_{obs}(2)$, then they should be the barrier to the rotation ($\Delta G^{\ddagger}_{rot}$). On the other hand, if $\Delta G^{\ddagger}_{obs}(2) - \Delta G^{\ddagger}_{obs}(1) \geq 15.5$ kJ mol^{-1}, $\Delta G^{\ddagger}_{obs}(1)$ should be the barrier to path I and $\Delta G^{\ddagger}_{rot}$ should be greater than or equal to $\Delta G^{\ddagger}_{obs}(2)$. From the results shown in Table that $\Delta G^{\ddagger}_{obs}(2) - \Delta G^{\ddagger}_{obs}(1) = 21.4$ kJ mol^{-1} > 15.5 kJ mol^{-1}, it is concluded that $\Delta G^{\ddagger}_{obs}(1)$ (52.7 kJ mol^{-1}) is the barrier to path I and that the barrier to the rotation for 1 and 2, i.e. $\Delta G^{\ddagger}_{rot}$, is greater than or equal to $\Delta G^{\ddagger}_{obs}(2)$ (74.1 kJ mol^{-1}).

The above discussion is further supported by the following facts. In lower temperature all the peaks of 1 further split into two peaks with intensity ratio about 85 : 15. At -117 °C one of the methyl signals split to a large extent ($\Delta\nu$ = 209.5 Hz) to give the weaker peak at higher field, which was unequivocally assigned to the axial methyl group from its δ value (11.9).[14] In contrast, 2 showed no splitting at lower temperature till -120 °C. These results strongly suggest that the lower temperature process involves slow interchanges between Gee and Gea. In 1 the 1,3-diaxial methyl-hydrogen interaction shifts the equilibriums Gee- $\rightleftarrows$ Gea+ and Gee+ $\rightleftarrows$ Gea- moderately in favor of Gee's, while in 2 the 1,3-diaxial methyl-methyl interaction biases the equilibrium nearly completely in favor of Gee's so that no signal due to Gea's was detected although the process slowed down.

References and Notes

1) J.R.Fletcher and I.O.Sutherland, J. Chem. Soc. Chem. Commun., 1969, 706. 2) J.E.Anderson, D.L. Griffith, and J.D.Roberts, J. Am. Chem. Soc., 91, 6371 (1969). 3) M.J.S.Dewar and W.B.Jennings, J. Am. Chem. Soc., 95, 1562 (1973). 4) R.A.Jones, A.R.Katritzky, K.A.F.Record, and R.Scattergood, J. Chem. Soc., Perkin Trans. 2, 1974, 406. 5) Y.Shvo, "The Chemistry of Hydrazo, Azo, and Azoxy Groups", ed by S.Patai, Interscience Publishers, New York (1975), part 2, p.1017. 6) Y.Nomura, K.Ogawa, Y.Takeuchi, and S Tomoda, Chem. Lett., 1978, 271. 7) Synthesis of 2 will be reported in the full paper. 8) ^{13}C NMR spectra were measured with a JEOL FX-90Q. 9) P.Rademacher and H. Koopmann, Chem. Ber., 108, 1557 (1975). 10) S.F.Nelsen and W.C.Hollised, J. Org. Chem., 45, 3609 (1980). 11) Energy difference between Gee and Tee (ref.5) is expected to be larger than the energy of 1,3-diaxial methyl-hydrogen interaction (ref.13). 12) E.L.Eliel, N.L.Allinger, S.J.Angyal, and G.A.Morrison, "Conformational Analysis", Interscience Publishers, New York (1965), Chap. 2. 13) E.L.Eliel and D.Kandasmay, Tetrahedron Lett., 1976, 3765. 14) D.Wendisch, H.Feltkamp and U. Scheidegger, Org. Magn. Reson., 5, 129 (1973).

(Received January 13, 1981)