

# Unsaturated diaziridines Thermal Cleavage Possibilities: Disrotatory or Conrotatory?

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**Abstract:** Ab initio calculations are carried out at UB3LYP/6-311++G (3df, 2p) levels of theory, on electrocyclic thermal cleavage of four (*R*) derivatives of diaziridines,  $1_{X-R}$ , to their corresponding (*Z*) and (*E*) azomethine imides ( $2_{X-Z}$ ,  $2_{X-E}$ ,  $3_{X-Z}$  and  $3_{X-E}$ ), where X = -H, -Me, -*t*-Bu and -Ph. Cleavage of  $3_{X-R}$  Series to  $3_{X-Z}$  (Path 3) emerged as the more favored, for producing the most stable products,  $3_{X-Z}$ . In IRC calculations that were shown in Path 3 and 4, C<sub>6</sub>-N<sub>5</sub> bond was cleavage, before reaching reaction rate determining step (transition state).

**Keywords:** diaziridines; azomethine imides; electrocyclic; thermal cleavage; conrotatory; IRC

## 1 Introduction

Thermal cleavages of unsaturated diaziridines in this manuscript are deliberate and compared with our recent work on saturated diaziridines [1].

Recent papers absorb our attention [2]. In first paper was reported that bicyclic allyl anion obtained at room temperature by rearrangement of tri-cyclic anion, in a forbidden disrotatory process (Scheme 1). Later paper supposed an initial conrotatory motion is therefore proposed to operate in the ring opening of the cyclopropyl anion. When the change in the sense of this rotation comes to pass; the system has already crossed the transition state. In contrast to bicyclic allyl anion that has only one possible product, we select diaziridines that has two possible products *via* four paths. Our results confirm that in both reaction paths (Path 3 and 4), before reaching transition state (determining reaction rate), C-N<sub>1</sub> bond cleavage.

The opportunity of pericyclic reactions commonly can be established, consistent with the Woodward-Hoffmann rules. For thermally electrocyclic reactions wherein a ring is opened (or ylene; ethylidene; 2,2-dimethylproplidene and benzylidene). Although formation of another azomethine imides (path 1 and 2): (*Z*) and (*E*) isomers of 1- (Y)-1,2-dihydro-pyrazol-3-one:  $2_{X-Z}$ ,  $2_{X-E}$  are possible. Here we will demonstrate formation of azomethine imides (path 3

formed), systems having odd- and even-numbered electron are predicted to endure disrotatory or conrotatory movements, respectively [2].

Azomethine imides are the product of cleavage of diaziridines and in 1,3-dipolar cycloadditions with dipolarophiles produce five membered rings [3]. Diaziridines react with alkenes to give N-protected aziridines directly. Halogenated diazirines are applied as: photolabel mimics of the inhaled haloalkane anesthetics, potential one-heteroatom transfer agents to olefins, and precursor of carbene synthesis [4].

## 2 Problem Formulations

In an electro-cyclic ring opening process, heating cleavages diaziridines: (6*R*)-X-1,5-diazabicyclo [3.1.0]hexan-3-en-2-one ( $1_{X-R}$  and/or  $1_{X-S}$ ; where X = H, methyl, *t*-butyl and phenyl), to their corresponding azomethine imides (path 3 and 4) : (*Z*) and (*E*) isomers of 2- (Y)-1, 2-dihydro-pyrazol-3-one:  $3_{X-Z}$ ,  $3_{X-E}$  (where, Y = meth

and 4):  $3_{X-Z}$ ,  $3_{X-E}$  is most favored both thermodynamically and kinetically.

## 2.1 Computational methods

Using Gaussian 98 system of programs [5] with basis set of McGrath, Curtiss included the diffuse functions (6-311++G (3df, 2p)) through density functional theory (UB3LYP) was selected, with the Becke three-parameter exchange functional [6] and the nonlocal correlation functional of Lee, Yang, and Parr for obtaining more accurate values of structures and energies [7]. DFT are selected among all methods, because it is less common to find any significant spin contamination in DFT calculations, even when unrestricted Kohn-Sham orbitals are used. In our DFT calculations, all of the  $\langle S^2 \rangle^1$  values, before and after annihilation step are equal to 0.00 and 0.00, respectively.

In order to find transition states, Keyword "QST3" are used. Also reaction path are followed by IRC to confirm transition states related to corresponding minimums [8]. Frequency calculations are carried out for determination of thermodynamic properties of stationary species. For minimum state structures, only real frequency values and for transition state structures one imaginary frequency values are accepted [9].

## 3 Problem Solution

Thermodynamic data are calculated at UB3LYP/6-311++G (3df, 2p) levels of theory for  $1_{X-R}$ ,  $1_{X-S}$ ,  $2_{X-E}$ ,  $2_{X-Z}$ ,  $3_{X-E}$ , and  $3_{X-Z}$  (Fig. 1). These data include: sum of electronic and thermal energies (E), sum of electronic and thermal enthalpies (H), sum of electronic and thermal Gibbs free energies (G) for all of the ground state which are obtained by the FREQUENCY option of the Gaussian 98 program.

Using the above data changes of activation electronic energies ( $\Delta E^\ddagger$ ); enthalpies of activation ( $\Delta H^\ddagger$ ) and Gibbs activation free energies ( $\Delta G^\ddagger$ ) are calculated for Path 3 and 4 (Table 1).

Relative energies ( $E_r$ ), enthalpies ( $H_r$ ) and free energies ( $G_r$ ) for all substituents (X) are presented in Table 2. This Table facilitates comparisons between ground states within Series. It is subdivided into 12 boxes. Each box represents relative  $E_r$ ,  $H_r$  and  $G_r$  values corresponding to a specific substituent (X). The lowest entry in each box is set at zero. Others are adjusted accordingly (Table 2).

<sup>1</sup> Spin Contamination negligible if the value of  $\langle S^2 \rangle$  differ from  $s(s+1)$  by less than 10%.

Molecules studied in this manuscript have singlet multiplicity thus their  $s(s+1) = 0(0+1) = 0$

The least preferred routes appeared to be conversion of  $1_{X-R}$  Series to  $2_{X-Z}$  (Path 1) and/or  $2_{X-E}$  (Path 2). This is due to huge instability of the  $2_{X-Z}$  and  $2_{X-E}$ , as well as the difficulty of cleavage the  $C_6-N_1$  bond in  $1_{X-R}$ . The difficulty is attributed to the regioselectivity for Cleavage of C-N bond in  $1_{X-R}$ . It means that cleavage of  $C_6-N_5$ , closer to double bond conjugated with carbonyl group, produces more stable azomethine imides ( $3_{X-Z}$  and  $3_{X-E}$ ) relative to cleavage of  $C_6-N_1$  that closer to carbonyl group, produces less stable azomethine imides ( $2_{X-Z}$  and  $2_{X-E}$ ). This is due to ability of double bond conjugated with carbonyl group in accommodates of generated negative charge during formation of  $3_{X-Z}$  and  $3_{X-E}$  on nitrogen atom *via* resonance forms. Calculated charge on oxygen in  $2_X$  and  $3_X$  confirm above [10].

For all substituents, between two *Z* and *E* isomer of  $3_X$ , former isomer more stable than later. Also between two less stable *Z* and *E* isomer of  $2_X$ , former isomer stable than later. This is for lower steric effect in *Z* isomer. Steric effect between X substituent and carbonyl's oxygen in *E* isomers, cause these isomers have higher energy relative to *Z* isomers. Therefore greater X substituent with higher steric effect, produce more energy difference between *Z* and *E* isomers (Table 2;  $\Delta E_r$  ( $3_{Ph-E}-3_{Ph-Z}$ ) = 6.93 >  $\Delta E_r$  ( $3_{t-Bu-E}-3_{t-Bu-Z}$ ) = 5.81 >  $\Delta E_r$  ( $3_{Me-E}-3_{Me-Z}$ ) = 1.73). Similar results are obtained for  $2_{X-E}$  and  $2_{X-Z}$ .

Finally Between two diaziridenes, ones that their bulky groups on  $C_6$  in three memberd ring, has exo position  $1_{X-R}$ , more stable than other (Fig. 1). The order of energy barriers in both Path are: (Ph < Me < t-Bu < H). In  $1_{Ph-R}$ , energy barriers of both paths are the lowest among all substituent. These are due to stabilizing effect of phenyl ring (Fig. 2) on transition states structures *via* delocalization. Shorter  $C_6-Ph$  bond length in transition state path 1 and 2 (1.444, 1.439) relative to reactant (1.491) proves this claim. Alkyl substituents due to Hyper-conjugation effect have lower energy barriers relative to -H substituent. These effect cause positive charges that grow on iminum group, delocalized and consequently energy barrier dropped. -t-Bu relative to -Me substituent is a bulky group. Therefore its energy barrier relative to -Me is higher. Substituent -H because of absence of resonance and hyper-conjugation effects has highest energy barrier.

Our calculated energy barriers for each substituent (X) in Path 3 and 4 are similar to each other approximately (Table 1); therefore both  $3_{X-E}$  and  $3_{X-Z}$  in the equivalent quantity will be produced as cited in literature. IRC calculations show in both reaction paths (Path 3 and 4), before reaching reaction rate determining step (TS), C<sub>6</sub>-N<sub>5</sub> bond cleavage initially is conrotatory compliant with the Woodward-Hoffmann rules. Also these calculations show with progressing of ring opening, C-N bond cleavage in reaction rate determining step have “disrotatory-like” and “conrotatory-like” reaction path, for Path 3 and Path 4, respectively. When the change in the sense of this rotation for path 3 (quasi-disrotatory path) takes place, the system has already crossed the transition state, and the breaking bond distance is 2.173 Å. Only conrotatory transition structures were located by B3LYP/6-311++G (3df, 2p) computations for the electrocyclic ring opening of diaziridines in both path. These are not consistent with considered disrotatory rotation rearrangement of cyclopropyl anions fused to bicyclic structures (Scheme 1) by M. Leivers and colleague. But our results are consistent with those of R. de Lera and co-workers [2].

#### 4 Conclusion

Barriers of electro-cyclic thermal cleavage of  $1_{X-R}$  to  $3_{X-E}$  (Path 4) relative to  $1_{X-R}$  to  $3_{X-Z}$  (Path 3) have greater values. This is due to two reasons:

- The disrotatory motion of substituted C<sub>6</sub>-N<sub>1</sub> that is opposite to the lone pair of N<sub>5</sub> is considered to be favored over the conrotatory because it pushes the σ-electrons away from the lone pair of N<sub>5</sub> [11].
- Transition states of Path 2 and Path 1 are similar to  $3_{X-E}$  and  $3_{X-Z}$  (IRC calculations results), respectively. Consequently, because of slightly higher energies of  $3_{X-E}$  relative to  $3_{X-Z}$  energy barriers of path 4 are larger than path 3.

Important related hardness principle also proposed by Pearson is the maximum hardness principle (MHP)<sup>2</sup> which states that, “there seems to be a rule of nature that molecules arrange themselves so as to be as hard as possible”. It has been shown that the validity of the HSAB<sup>3</sup> principle somehow demands that of the MHP [12-15]. Hardness (η) for  $3_{X-Z}$  and corresponding

<sup>2</sup>  $\eta = \frac{\epsilon_l - \epsilon_H}{2}$  Where  $\epsilon_l$  and  $\epsilon_H$  are the lowest unoccupied and highest occupied molecular orbital energies, respectively.

<sup>3</sup> Hard Soft Acid Base

transition states are calculated. These data for minimums are greater than transition states.

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Table 1

Changes of activation electronic energies ( $\Delta E^\ddagger$ ); enthalpies of activation ( $\Delta H^\ddagger$ ) and Gibbs activation free energies ( $\Delta G^\ddagger$ ) for electrocyclic thermal cleavage of  $1_{X-R}$  to  $3_{X-Z}$  (Path 3) and  $1_{X-R}$  to  $3_{X-E}$  (Path 4), calculated UB3LYP/6-311++G (3df, 2p) level of theory.

| Path   | Conversion               | kcalmol <sup>-1</sup> |                     |                     |
|--------|--------------------------|-----------------------|---------------------|---------------------|
|        |                          | $\Delta E^\ddagger$   | $\Delta H^\ddagger$ | $\Delta G^\ddagger$ |
|        | $1_H$ to $2_H$           | 36.18                 | 36.18               | 35.92               |
| Path 3 | $1_{Me-R}$ to $3_{Me-Z}$ | 23.14                 | 23.14               | 23.01               |
|        | $1_{Bu-R}$ to $3_{Bu-Z}$ | 26.22                 | 26.22               | 26.90               |
|        | $1_{Ph-R}$ to $3_{Ph-Z}$ | 19.71                 | 19.71               | 20.01               |
|        | $1_H$ to $3_H$           | 25.10                 | 25.10               | 24.96               |
| Path 4 | $1_{Me-R}$ to $3_{Me-E}$ | 25.14                 | 25.14               | 24.64               |
|        | $1_{Bu-R}$ to $3_{Bu-E}$ | 28.32                 | 28.32               | 28.90               |
|        | $1_{Ph-R}$ to $3_{Ph-E}$ | 21.42                 | 21.42               | 21.89               |

Table 2

Relative energies ( $E_r$ ), enthalpies ( $H_r$ ) and Gibbs free energies ( $G_r$ ) for conversions of substituted diaziridine **1** to corresponding azomethine imides **2** via UB3LYP/6-311++G\*\* for  $1_{X-R}$ ,  $1_{X-S}$ ,  $2_{X-Z}$ ,  $2_{X-E}$ ,  $3_{X-Z}$  and  $3_{X-E}$  (where X = H, methyl, t-butyl and phenyl). The lowest value of E, H and G for each substituent (X) is set at zero.

| X    | Structure    | kcalmol <sup>-1</sup> |       |       |
|------|--------------|-----------------------|-------|-------|
|      |              | $E_r$                 | $H_r$ | $G_r$ |
| H    | $1_H$        | 16.80                 | 16.80 | 17.48 |
|      | $2_H$        | 7.27                  | 7.27  | 7.56  |
|      | $3_H$        | 0.00                  | 0.00  | 0.00  |
| Me   | $1_{Me-S}$   | 22.12                 | 22.12 | 22.31 |
|      | $1_{Me-R}$   | 18.15                 | 18.15 | 18.20 |
|      | $2_{Me-E}$   | 12.37                 | 12.37 | 12.57 |
|      | $2_{Me-Z}$   | 8.28                  | 8.28  | 7.50  |
|      | $3_{Me-E}$   | 3.66                  | 3.66  | 1.73  |
|      | $3_{Me-Z}$   | 0.00                  | 0.00  | 0.00  |
| t-Bu | $1_{t-Bu-S}$ | 25.61                 | 25.61 | 26.66 |
|      | $1_{t-Bu-R}$ | 15.42                 | 15.42 | 15.99 |
|      | $2_{t-Bu-E}$ | 14.23                 | 14.23 | 14.48 |
|      | $2_{t-Bu-Z}$ | 7.91                  | 7.91  | 8.23  |
|      | $3_{t-Bu-E}$ | 5.73                  | 5.73  | 5.81  |
|      | $3_{t-Bu-Z}$ | 0.00                  | 0.00  | 0.00  |
| Ph   | $1_{Ph-S}$   | 28.29                 | 28.29 | 28.52 |
|      | $1_{Ph-R}$   | 22.40                 | 22.40 | 22.34 |
|      | $2_{Ph-E}$   | 14.14                 | 14.14 | 14.16 |
|      | $2_{Ph-Z}$   | 7.43                  | 7.43  | 7.58  |
|      | $3_{Ph-E}$   | 7.14                  | 7.14  | 6.93  |
|      | $3_{Ph-Z}$   | 0.00                  | 0.00  | 0.00  |

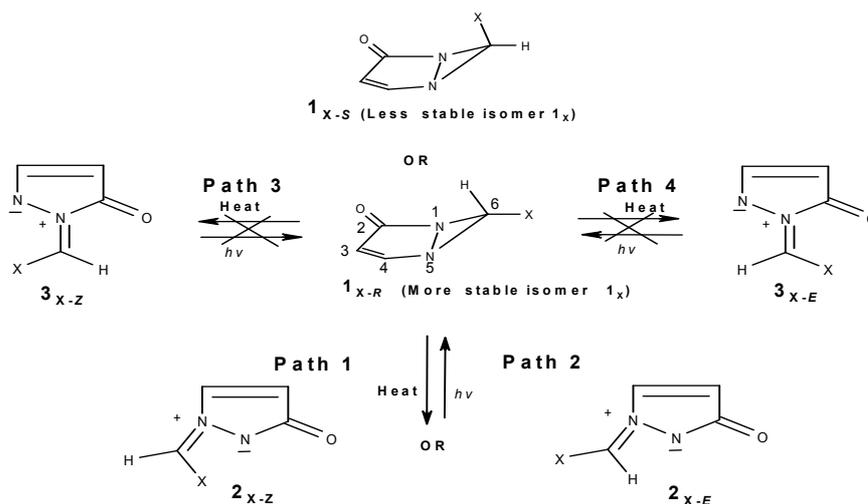


Fig. 1 Four possible routes for electrocyclic thermal cleavage of derivatives of (*R*) diaziridines ( $1_{X-R}$  and  $1_{X-S}$ ), to their corresponding (*Z*) and (*E*) azomethine imides ( $2_{X-Z}$ ,  $2_{X-E}$ ,  $3_{X-Z}$  and  $3_{X-E}$ ), where X = H, methyl, *t*-butyl and phenyl.

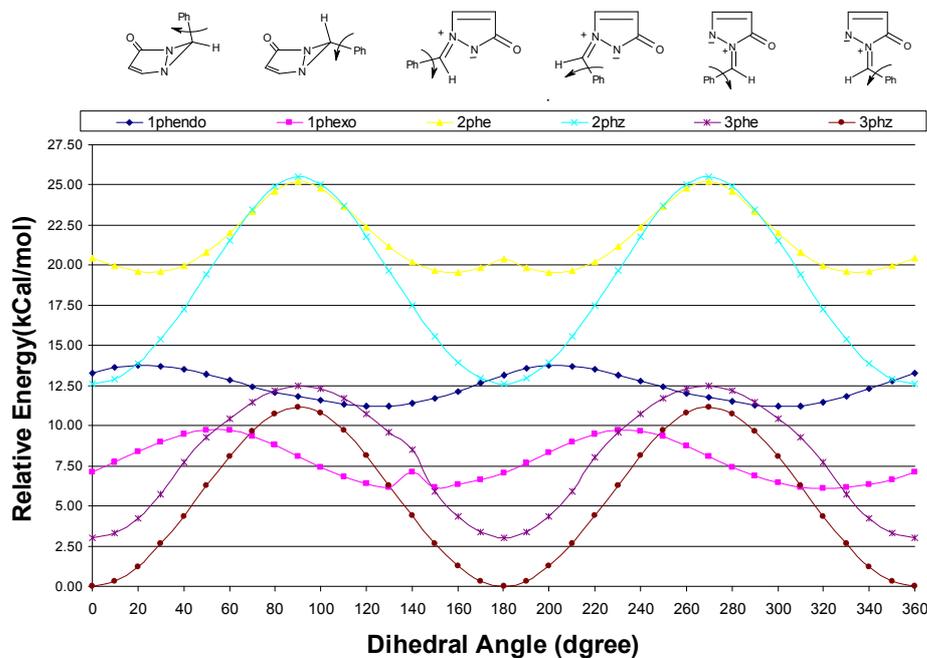
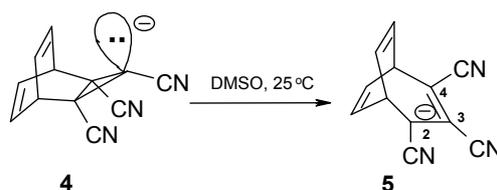


Fig. 2 Change of energy ( $\text{kcal mol}^{-1}$ ) as a function of phenyl (Ph) rotation in  $1_{X-R}$ ,  $1_{X-S}$ ,  $2_{X-Z}$ ,  $2_{X-E}$ ,  $3_{X-Z}$  and  $3_{X-E}$ . Effect of X = Ph substituent rotation on energy: in all compound, when its dihedral angle is planar energy is minimum.



Scheme 1 Rearrangement of cyclopropyl anions fused to bicyclic structures [2]