

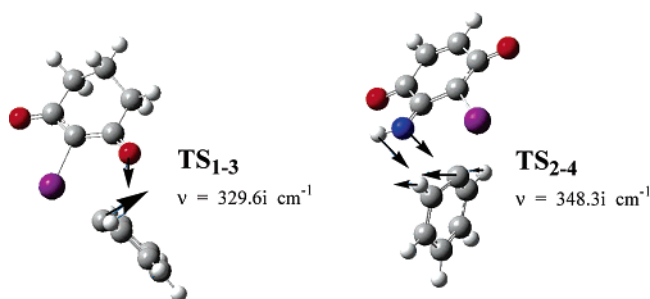
A DFT Study on the Thermal Aryl Migration in Aryliodonium Ylides. Support for a Concerted Mechanism

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A DFT study on the intramolecular thermal phenyl migration in iodonium ylides supports a concerted mechanism. In contrast to the two, different than each other, suggested mechanisms, involving only intermediates, this study indicates a single-step, transition-state one—involving a five-membered cyclic ring—with no intermediates. The frontier-orbital-controlled migration also confirms the different thermal behavior of two different ylides.

Aryliodonium ylides of β -dicarbonyl compounds represent an important class of hypervalent iodine compounds¹ and find many applications as flexible building blocks in organic synthesis.² Aryliodonium ylides exhibit a broad spectrum of reactivity, depending mostly on the nature of the β -dicarbonyl moiety. One of their most known reaction pathways is the iodine to oxygen migration of the aryl group under thermal conditions (Scheme 1), always taking place at the *ipso* to I carbon of the aryl group.

This migration is observed mostly on ylides of cyclic 1,3-diketones as well as on aryliodonium derivatives of phenolates,

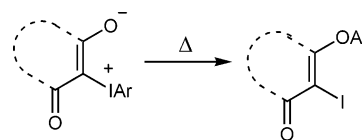
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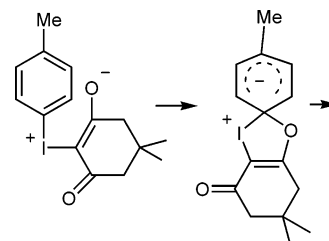
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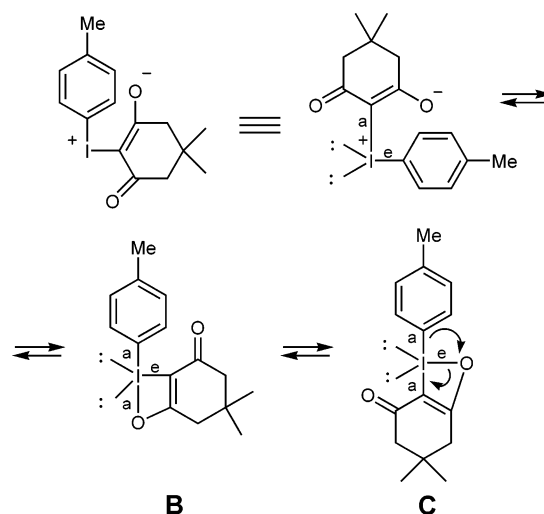
SCHEME 1. Iodine to Oxygen Thermal Migration of the Aryl Group



SCHEME 2. Nozaki's Proposed Intermediate



SCHEME 3. Moriarty's Proposed Reaction Pathway and Intermediates

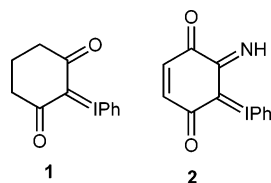


compounds of 1,4-zwitterionic structure.³ Regarding the mechanism of this migration, Nozaki et al.⁴ suggested that it proceeds through a five-membered cyclic intermediate, a mechanistic pathway that was generally accepted (Scheme 2). Very recently, Moriarty⁵ suggested that this migration proceeds by a ligand coupling mechanism analogous to the one proposed for S_NAr substitution in iodonium salts, with four-membered cyclic intermediates (Scheme 3). Since, to our knowledge (a) no real evidence in favor of the one or other path exists and (b) both pathways constitute qualitative suggestions, not taking into account the available experimental data of the corresponding ylides, we tested both reaction pathways using electronic structure calculation methods.

For this purpose, all intermediates involved in both suggested mechanisms were checked for their stability; the phenyl group

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SCHEME 4. The Model Ylides **1** and **2**

migration was studied using the phenyliodonium ylide of 1,3-cyclohexanedione (**1**) as a model (Scheme 4). Experimental results exist for the corresponding ylide of dimedone, but the two methyl groups at position 5 were omitted in **1**, as their inclusion would unnecessarily increase the optimization time. Moreover, by the same approach, we tried to explain the spontaneous migration of an aryl group from iodine to nitrogen at room temperature, observed⁶ in phenyl iodonium ylides of 2-amino-1,4-quinones, using the parent compound **2** as a model. The reaction steps involved in the entire thermal course of **1** and **2** have been scrutinized, and the transition states have been fully identified by monitoring the corresponding geometric and energetic reaction profile.

All stationary points (reactants, transition states, and products) found in the potential energy surfaces (PES) were fully optimized at the B3LYP/LANL2DZ level of theory as implemented in the Gaussian98 suite of programs.⁷ For a further confirmation, the full structure optimization and the energetic reaction profiles of the two systems were also evaluated at the B3LYP/6-31G(d) level of theory (a 3-21G basis set was used for the I atom); their energetic data are given in parentheses. The B3LYP method provides good descriptions of reaction profiles, including geometries, heats of reactions, and barrier heights.⁸ To speed optimization at the DFT level, the starting geometries of all stationary points were those calculated at the HF/3-21G level of theory. Analytical frequencies were calculated at the same level of theory, and the nature of the stationary points was determined in each case according to the number of the negative eigenvalues of the Hessian matrix. Unless otherwise stated, reaction enthalpies, $\Delta_R H$, are used for the discussion on the relative stabilities of the chemical structures considered, and Gibbs free energies, ΔG^\ddagger , are used for the evaluation of the activation energies. Moreover, the correct transition states have been confirmed by intrinsic reaction coordinate (IRC) calculations, while intrinsic reaction paths (IRPs) were traced from

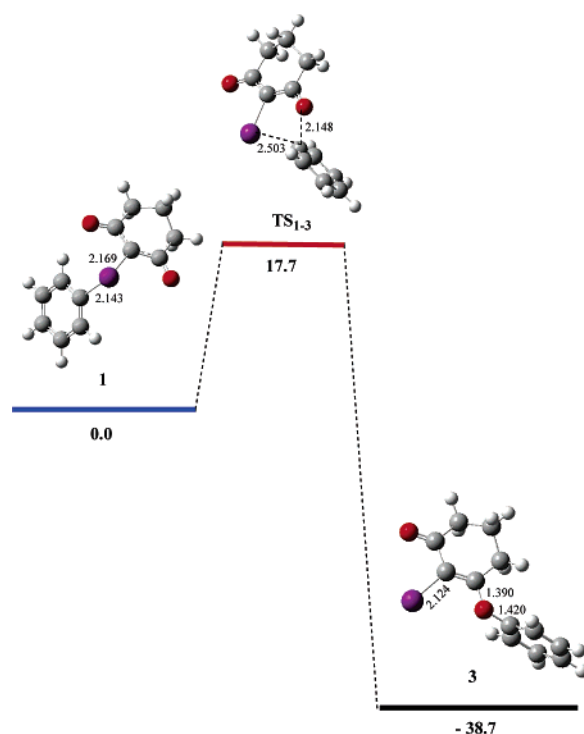


FIGURE 1. Nozaki's (**1**) reaction profile along with selected structural data.

the various transition structures to make sure that no further intermediates exist.⁹

All intermediates suggested by Nozaki and Moriarty (B and C of Scheme 3) were checked for their stability; the corresponding structures were given as the initial ones in the above DFT level calculations. However, all of them yielded reactant **1** as their final global minimum structures. It is worth mentioning here that, despite the nonexistence of Nozaki's suggested intermediate at the DFT levels tested, the latter resembles closely the TS_{1-3} (vide infra) transition-state structure of our study. The nonexistence of two Moriarty's four-membered intermediates at the DFT level, however, could be attributed to the greater stability^{2a} of the five-membered ring ones, compared to the corresponding four-membered ones.

In an attempt to further confirm the above findings, the calculated structural details and the reaction profiles for the iodine to O and/or N thermal phenyl migration in **1** and **2** (given in Figures 1 and 2, respectively) were examined next. The transformation of the reactants **1** and **2** to the final products **3** and **4** proceeds via the transition states TS_{1-3} and TS_{2-4} , with activation barriers of 17.7(19.7) and 6.4(9.3) kcal/mol, respectively. This suggests that, while the thermal transformation of **2** is almost barrierless, occurring at room temperature, **1** requires a gentle heating in solution, in excellent agreement with the experimental findings of these compounds.^{3,6} The normal coordinate vectors (arrows) of the vibrational modes, corresponding to the imaginary frequencies of TS_{1-3} and TS_{2-4} at 329.6i and 348.3i, respectively, show that, in both cases, the dominant motions involve the formation of one five-membered ring containing weak C–I and C–O and/or C–N linkages. The thermal phenyl migration in **1** is a medium exothermic process

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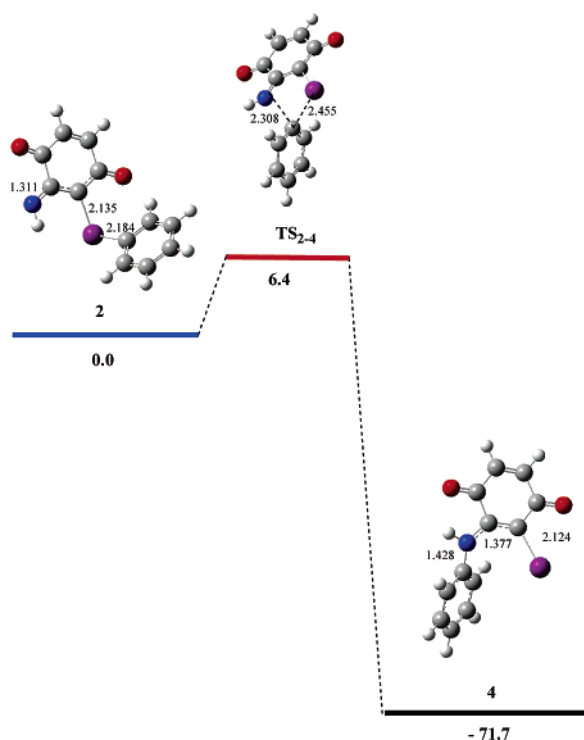
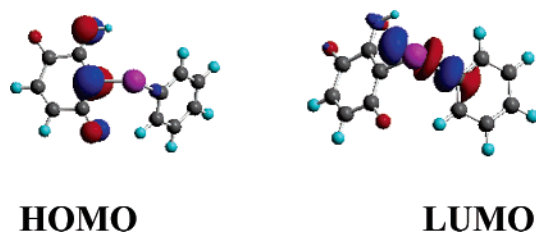


FIGURE 2. Ylide's **2** reaction profile along with selected structural data.

$[\Delta_R H = 38.7(37.7) \text{ kcal}\cdot\text{mol}^{-1}]$ and a strong one $[\Delta_R H = 71.7(63.6) \text{ kcal}\cdot\text{mol}^{-1}]$ in **2**. It is worth mentioning here that IRPs traced from the various transition structures verified that no further intermediates exist.

Moreover, calculated natural net atomic charges on the two carbonyl O atoms of the 1,3-diketonic moiety in **1** and on the carbonyl O and imino N atoms of the corresponding one in **2** are equal to -0.62 and -0.65 , and -0.63 and -0.62 |e|, respectively. This negative charge delocalization in both ylides, along with the high positive charges on the I atom ($+0.90$ and $+0.88$ |e|, respectively), could account well for their stabilization. In addition, the negative natural net atomic charges on the *ipso* to I aryl carbon atoms (-0.24 and -0.22 |e|, respectively) could (a) exclude a charge-controlled mechanism

SCHEME 5. The HOMO and LUMO of **2**



for the intramolecular thermal phenyl migration and (b) account well for the primarily ionic I-*ipso* bonding in both ylides, verifying their thermal reactivity well. However, **1** and **2** show analogous HOMOs and LUMOs, delocalized mainly on the 1,3-diketonic moiety of their ring and on the I and the *ipso* atoms, respectively (Scheme 5). Hence, a frontier-orbital-controlled mechanism, through an intramolecular HOMO-LUMO interaction, seems probable in either of them. The stronger location of the HOMO on the N than on the carbonyl O atom in **2** could be in line with the *ipso* attack at this center. Moreover, the better HOMO-LUMO energy matching in **2** (0.1219 au) than in **1** (0.1502 au) could further verify the easier thermal migration observed in the former.

In summary, DFT calculations on the intramolecular thermal phenyl migration in iodonium ylides reveal a concerted mechanism. In particular, contrary to Nozaki's and Moriarty's, different than each other, suggested mechanisms—involving only intermediates—the novel mechanism is (a) a transition-state single-step one—with a five-membered cyclic ring and no intermediates, and (b) a frontier orbital rather than a charge-controlled one. However, Nozaki's suggested intermediate resembles closely our TS_{1-3} transition-state structure; Moriarty's four-membered suggested intermediates do not exist at the DFT levels tested. The novel mechanism also fully confirms the different experimental data of two different ylides.

Supporting Information Available: Cartesian coordinates and energies of all stationary points are compiled in Tables S1 (3 pages) and S2 (1 page), respectively. This material is available free of charge via the Internet at <http://pubs.acs.org>.

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