

## Theoretical Study of Impact of Side Substituent Effect on Intramolecular Proton Transfer of Perylenequinone

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**Abstract:** Semi-empirical molecular orbital theory AM1 method is employed to study the ortho-position substituent impact on intramolecular proton transfer reaction of perylenequinone. The calculation demonstrates that the perylenequinone molecule is of stable structure, and all substituents may cause the decrease of barriers for the hydrogen transfer reaction.

**Keywords:** Perylenequinone; AM1 method; proton transfer; substituent effect.

Perylenequinoids are photosensitive. Because they can effectively kill tumor cells and inhibit HIV viruses, people have paid much attention to them in recent years and expected them to become a new kind of medicine for treatment of tumor and AIDS<sup>1</sup>.

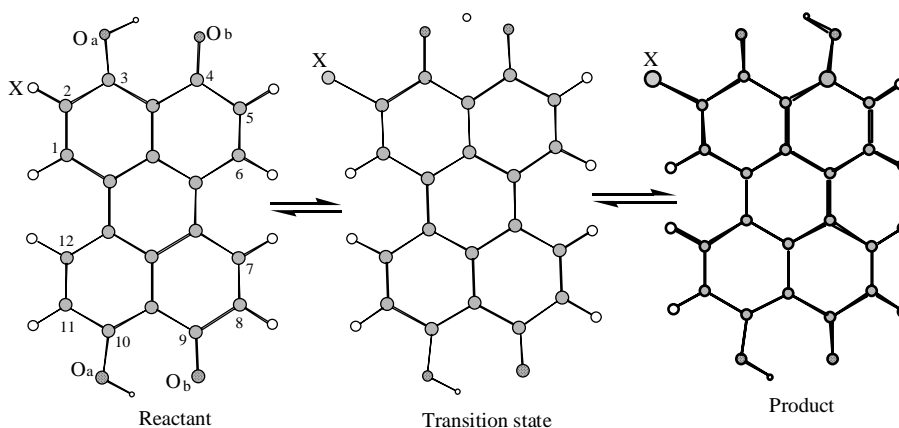
The reason why it is possible to use Perylenequinoids as medicine is that they possess excellent photosensitive properties such as good thermal stability, high level of <sup>1</sup>O<sub>2</sub> quantum yield, and easiness of purification, *etc*<sup>2-4</sup>. These performances are determined by their unique molecular structure (**Figure 1**). They may have intramolecular hydrogen transfer reaction between O<sub>a</sub> and O<sub>b</sub> as shown in **Figure 1**. This proton transfer reaction plays an important role in keeping perylenequinoid's photosensitivity, therefore it is important on deciding the photosensitive mechanism to study the reaction of this transfer reaction. This paper theoretically studies the impact of ortho-position substituents of perylenequinone on mechanism of proton transfer process. As a medicine, the changes of substituents have strong impact on properties and activities of medicines. Our study lays a theoretical foundation for developing and applying these substances, and explaining phenomenon in experiments.

Structures of all stationary points are obtained by full optimization of geometric variables using AM1 method<sup>5</sup>. Vibrational analysis of 7 transition states are calculated; only one negative eigenvalue is identified in their force constant matrix for each transition state, and its corresponding vibrational mode points respectively to the reactant and product. Gaussian 94<sup>6</sup> is used to conduct all calculations.

**Figure 1** presents reactions of intramolecular proton transfer of perylenequinone for different substituents: X=Br, Cl, F, CN, H, CH<sub>3</sub> (M), OCH<sub>3</sub> (OM). **Table 1** presents the heat of formations and reaction barriers for reactants, transition states and products.

**Table 1.** Energies and barriers of substances in reaction process (kJ/mol)

	Reactants	Transition state	Product	Reaction barriers
P-Br	-199.22	-119.81	-193.33	79.41
P-Cl	-250.98	-170.15	-245.23	80.83
P-F	-413.40	-328.19	-405.71	85.21
P-CN	-92.48	-10.095	-83.345	82.38
P-H	-240.30	-153.12	-227.35	87.18
P-M	-266.36	-182.81	-257.83	83.55
P-OM	-381.78	-297.30	-377.29	84.48

**Figure 1.** Intramolecular Proton Transfer of Perylenequinone

### Impact of substituent on barriers of hydrogen transfer reaction

From data in **Table 1**, it can be observed that for electron withdrawing substituents, when X=Br, Cl, F, as the increase of electric negativity of substituent, the barrier of proton transfer reaction increases relatively, which are 79.41, 80.83, 85.21 kJ/mol respectively. When X=CN, because of its conjugation effect on the ring, electrons on hydroxyl oxygen are stabilized, its barrier is 82.38 KJ/mol, which is higher than that of substituent Cl, but lower than that of substituent F. All the electron withdrawing substituents make the reaction barrier lower than perylenequinone.

For electron donating substituents, when X = CH<sub>3</sub> (M), OCH<sub>3</sub> (OM), it also makes the reaction barrier lower. Perylenequinone, which has no substituents, showed the highest barrier for the reaction. This indicates that any type of substituents, both electron withdrawing or donating, can lower the barrier of the proton transfer reaction.

### Substituent impact on charges of oxygen atoms related to hydrogen transfer

In proton transfer reaction, the net charges of the atoms related to the shift process play an important role. To show the difference of net charges for every substituents, we listed the charges in **Table 2**.

**Table 2** Charges of oxygen atoms related to hydrogen transfer (Unit: |e)

	Reactants		Transition states		Products	
	O <sub>b</sub>	O <sub>a</sub>	O <sub>a</sub>	O <sub>b</sub>	O <sub>a</sub>	O <sub>b</sub>
P-Br	-0.3376	-0.2378	-0.3435	-0.3530	-0.2445	-0.3318
P-Cl	-0.3372	-0.2379	-0.3443	-0.3530	-0.2457	-0.3493
P-F	-0.3341	-0.2355	-0.3429	-0.3513	-0.2432	-0.3253
P-CN	-0.3351	-0.2381	-0.3398	-0.3558	-0.2422	-0.3366
P-H	-0.3407	-0.2500	-0.3484	-0.3700	-0.2468	-0.3517
P-M	-0.3421	-0.2529	-0.3492	-0.3717	-0.2476	-0.3524
P-OM	-0.3377	-0.2257	-0.3502	-0.3402	-0.2464	-0.3145

It can be seen that both electron-withdrawing (X=Br, Cl, F, CN) and electron-donating groups (X=OM) decrease the negative charge of O<sub>a</sub> and O<sub>b</sub>, that may lessen the bond between O<sub>a</sub> and proton in reactant and makes the reaction easier, which is consistent with the reaction barrier listed in **Table 1**.

It is also indicated in **Table 2** that for electron withdrawing substituents, the negative charge of O<sub>a</sub> of reactants has good relationship with the reaction barrier (see **Table 1**), the more negative of O<sub>a</sub> for the substituent, the lower of the reaction barrier, namely the regularity of the net charge of O<sub>a</sub> for P-Br, P-Cl, P-CN and P-F:  $-0.3376 < -0.3372 < -0.3351 < -0.3341$  is consistent with the regularity of reaction barrier for these compounds:  $79.41 < 80.83 < 82.38 < 85.2$  KJ/mol<sup>-1</sup>.

## Conclusion

Based on above calculations and discussion, the following conclusion can be made: The structure of perylenequinone molecule presents a conjugate system, which is important for the reaction.

Both electron-withdrawing and electron-donating substituents at the ortho-position of perylenequinone make the proton transfer reaction easier, which may be caused by the conjugation of the rings. And both types of substituents may accelerate the photochemical reactions when they are used as medicines.

The negative charge of O<sub>a</sub> of reactants also has some sort of relationship with the reaction barrier, the more negative of O<sub>a</sub> for the substituent, the lower of the reaction barrier.

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**References**

1. Z. Diwu, *Photochem. Photobiol.* **1995**, *61*, 529.
2. T. Yamazaki and N. Ohta, *J. Phys. Chem.*, **1993**, *97*, 7870.
3. D. Freeman and F. Frolow, *J. Chem. Soc. Chem. Commun.*, **1994**, 891.
4. F. Gai and M. Fehr, *J. Phys. Chem.*, **1994**, *98*, 5784.
5. M. J. S. Dewar, E. G. Zoebisch and E. F. Healy, *J. Amer. Chem. Soc.*, **1985**, *107*, 3902.
6. M. J. Frisch, G. W. Trucks, H. B. Schlegel, P. M. W. Gill, B. G. Johnson, M. A. Robb, J. R. Cheeseman, T. Keith, G. A. Petersson, J. A. Montgomery, K. Raghavachari, M. A. Al-Laham, V. G. Zakrzewski, J. V. Ortiz, J. B. Foresman, J. Cioslowski, B. B. Stefanov, A. Nanayakkara, M. Challacombe, C. Y. Peng, P. Y. Ayala, W. Chen, M. W. Wong, J. L. Andres, E. S. Replogle, R. Gomperts, R. L. Martin, D. J. Fox, J. S. Binkley, D. J. Defrees, J. Baker, J. P. Stewart, M. Head-Gordon, C. Gonzalez, and J. A. Pople, *Gaussian 94, Revision E.1*, Pittsburgh PA, **1995**.

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