# CONFORMATIONAL ISOMERISM IN A CONFORMATIONAL POLYMORPH OF 2,5-DIBENZYLIDENECYCLOPENTANONE: CRYSTALLOGRAPHIC AND QUANTUM CHEMICAL STRUCTURES

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**Keywords:** polymorph; conformers; molecular packing; quantum chemical calculations; DFT/B3LYP; 2,5-dibenzylidenecyclopentanone

A new polymorph (II) of 2,5-dibenzylidenecyclopentanone (DBCP) has been obtained by slow evaporation of ethanol solvent at room temperature. Interestingly, two conformational isomers of the title compound with slight difference in their bond lengths, torsion angles and dihedral angles were found within the same crystal lattice of polymorph (II). The crystal structure of polymorph (II) showed monoclinic $P2_1$ space group with $a$ = 6.0983 (2) Å, $b$ = 14.9200 (7) Å, $c$ = 15.0740 (6) Å, V= 1368.69 Å$^3$, Z = 2 as compared to orthorhombic $C222_1$ space group with $a$ = 11.803 (2) Å, $b$ = 5.698 (4) Å, $c$ = 20.872 (2) Å, V= 1403.6 Å$^3$, Z = 4 for previously reported polymorph (I) crystallized in $CHC1_3$/MeOH solvent. The concomitant origin of polymorphism and conformational isomerism was credited to C-H···O, π-π and C-H···π interactions resulting in intriguing supramolecular sheet-like multilayered molecular packing of polymorph (II). The results of the complementary electronic structure calculations, performed by DFT/B3LYP method using 6-31G* basis set were found in good agreement with the experimental results.

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## Introduction

Polymorphism, a type of supramolecular isomerism is the ability of the same molecule to exist in more than one type of network superstructure resulting from interplay of kinetic and thermodynamic parameters and can therefore be related to structural isomerism at the molecular level.[1-8] The different nature of intermolecular forces, not only influence crystal packing but also affect physical, chemical and mechanical properties of the organic solid-state materials.[9-15] By slight variations in the crystallization environment such as temperature, solvent, using of additives and concentration; the same molecules can pack differently forming different crystal lattices or polymorphs.[5,16,17] The generality of this phenomenon can be estimated from this fact that 80-90% of active pharmaceutical ingredients are capable of existing in polymorphic forms[18] and hence may show distinguished physicochemical properties, bioavailabilities and therapeutic effects due to different arrangement of molecules in the crystal lattice.[19-21]

Molecules with conjugated backbone and spatially separated electron donor/acceptor functionalities have actively been investigated for their non-linear optical (NLO) and thermotropic properties.[22-28] Similar molecules with different substituents are also used as *in vivo* multiphoton fluorescent markers and in the control of blood coagulation pathways.[29] Among diverse conjugated systems recently explored, the molecular architectures having extended donor-(π-spacer)-acceptor-(π-spacer)-donor (D-π-A-π-D) motifs were found potential biophotonic materials.[30] The double Claisen-Schmidt condensation reaction of a ketone having two active α,α′ sites with two equivalents of aldehyde is the best method to prepare compounds with (D-π-A-π-D) motif, often referred to by their generic name of *bis*-chalcone [31]. Recently, desirable NLO properties were obtained from piperidone-based *bis*-chalcones.[30]

In recent years, chalcones in general[32] and *bis*-chalcones[33-38] in particular, showed a number of biological applications. Therefore, controlling the polymorphic properties of this D-π-A-π-D class of compounds is important in medicinal chemistry and this can be achieved through combined experimental and computational approach to understand the interplay of intermolecular interactions and relative stability of different polymorphic forms of a compound. Herein, we report both experimental and computational results of second conformational polymorph of 2,5-dibenzylide-necyclopentanone which show conformational isomerism i-e two independent molecules with slightly different bond lengths, torsion angles and dihedral angles are present in its unit cell. The geometric parameters of two polymorphic forms are also compared through quantum chemical computations.

## Experimental

### Synthesis

2,5-dibenzylidenecyclopentanone (DBCP) was prepared by the reaction of cyclopentanone with benzaldehyde in 1:2 ratio by continuous stirring for 6 hours at room temperature in methanolic sodium hydroxide [39]. The single crystal suitable for X-ray analysis was obtained by slow evaporation of its ethanolic solution at room temperature.

### X-ray Crystallography

Single crystal X-ray diffraction measurements for the title compound were carried out using Bruker APEX-II CCD area-detector equipped with the graphite monochromator at 140(2) K with MoK\α radiations ( λ = 0.71073 Å). Structure solved by direct methods[40] full-matrix least-squares refinement[40] on $F^2$ and 355 parameters for 5355 unique intensities ($R_{int}$ = 0.011). The crystal parameters are shown in Table 1. CCDC-983901 contains the supplementary crystallographic data for this paper.

**Table 1.** Crystallographic data for polymorph (II) of DBCP

| | |
|---|---|
| Crystal data | DBCP |
| CCDC Number | 983901 |
| $M_r$ | 516.60 |
| Crystal system, space group | Monoclinic, $P2_1$ |
| Temperature (K) | 140 |
| *a*, | 6.0983(2), |
| *b*, | 14.9200(7), |
| *c* (Å) | 15.0740 (6) |
| β (°) | 93.687 (3) |
| *V* (Å3) | 1368.69 (10) |
| *Z* | 2 |
| Radiation type | Mo Ka |
| *m* (mm-1) | 0.08 |
| Crystal size (mm) | 0.17 × 0.10 × 0.10 |
| **Data collection** | |
| Diffractometer | Bruker APEX-II CCD area-detector diffractometer |
| Absorption correction | Multi-scan (SADABS; Sheldrick, 1996) |
| $T_{min}$, $T_{max}$ | 0.568, 0.746 |
| No. of measured, independent and observed [I > 2s(I)] reflections | 11078, 5355, 2558 |
| $R_{int}$ | 0.246 |
| **Refinement** | |
| *R*[*F*2 > 2s(*F*2)], | 0.111, |
| w*R*(*F*2), | 0.335, |
| *S* | 0.98 |
| No. of reflections | 5355 |
| No. of parameters | 361 |
| No. of restraints | 1 |
| H-atom treatment | H-atom parameters constrained |
| $\Delta\rho_{max}$, $\Delta\rho_{min}$ (e Å-3) | 0.84, -0.54 |

### Computational Detail

The molecular structure of DBCP is optimized using DFT/B3LYP level of theory with 6–31G* basis set.[41-43] The initial guess of compound was first obtained from the X-ray coordinates. All calculations were performed using the ORCA 3.0.1 program package[44] with Gabedit graphical user interface[45] on a personal computer without specifying any symmetry for the title molecule.

## Results and Discussion

### Crystal structure of polymorph (II)

The crystal structure of polymorph (II) of 2,5-dibenzylidenecyclopentanone (DBCP) is shown in the ORTEP diagram with labeling in Figure 1. It crystallizes in the monoclinic P21 space group with Z = 2, Z' = 0 in contrast to the orthorhombic C2221 space group with Z = 4 for previously reported Polymorph (I).[39]

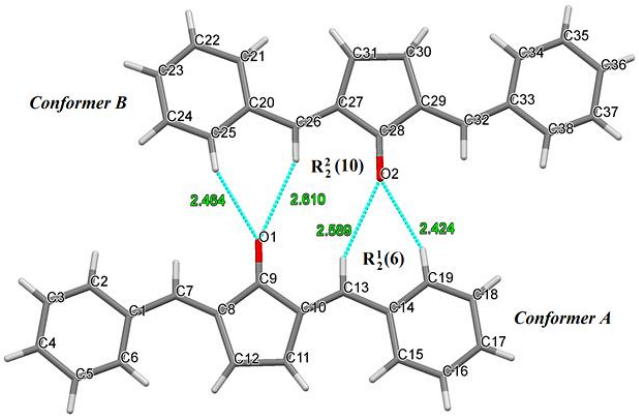


**Figure 1.** The crystal structure of polymorph (II) of DBCP having two conformational isomers.

Interestingly, in a unit cell of the polymorph (II), there are two different/independent molecules (called conformer A & conformer B) having slightly different bond lengths, dihedral angles and torsions angles. The peripheral phenyl rings and central cyclopentanone rings in both the conformers A & B are not coplanar. The angle between the least square planes of the rings containing the atoms C9 and C2, and C9 and C19 in conformer A = 5.67° and 5.68° and of the rings with C28 and C38, and C28 and C25 in conformer B = 3.87° and 3.38°. The Bond lengths for C=C-Car single bonds (C8-C9 1.496 Å, C10-C9 1.471 Å, C27-C28 1.463 Å, C29-C28 1.471 Å) in both the conformers are shorter than the normal single bond length due to conjugation and C=C-Car double bonds (C7-C8 1.320 Å, C10-C13 1.360 Å, C29-C32 1.368 Å, C26-C27 1.355 Å are also slightly different as compared to normal double bond length.[46] The bond lengths of carbonyl groups of two conformers are C9-O1 1.220 Å and C28-O2 1.254 Å, respectively. All the other bond lengths are also different in both the conformers. This difference in bond lengths, torsion angles and bond angles can be attributed to the varied amount of conjugation due to different conformations of two molecules.

Another important aspect of polymorph (II) of DBCP, other than having two different conformers in its unit cell, is its intriguing supramolecular sheet-like multilayered molecular packing stabilized mainly by C-H···O, π-π and C-H···π interactions (Figure 2a). Two conformers (A and B) are connected to each other in such a way that each A is connected with two B by means of cyclic $R_2^1(6)$ and $R_2^2(10)$ type C-H···O (C13-H13···O2= 2.589 Å, C19-H19···O2= 2.424 Å, C25-H25···O1= 2.464 Å, and C26-H26···O1= 2.610 Å) hydrogen bond motifs (Figure 1 & 2)[47]

and π-π (C9-C27 3.393 Å, C10-C28 3.339 Å, C13-C29 3.385 Å and C14-C32 3.381 Å) interactions [48] and vice versa making chains like structure (Figure 2b). Each 1D-supramolecular chain is further connected to the neighboring chain by means of H-H (C36-H36···H23-C23 2.393 Å) interactions[49,50] forming 2D-sheet like layer (Figure 2c). These sheet-like layers are then stacked one above the other by means of CH-π interactions (C22-C22···C16 2.891 Å)[48,51] forming sheet-like multilayered structure. It is interesting to mention here that chains of the every two neighboring layers are connected with each other in a head to tail fashion (Figure 2a).

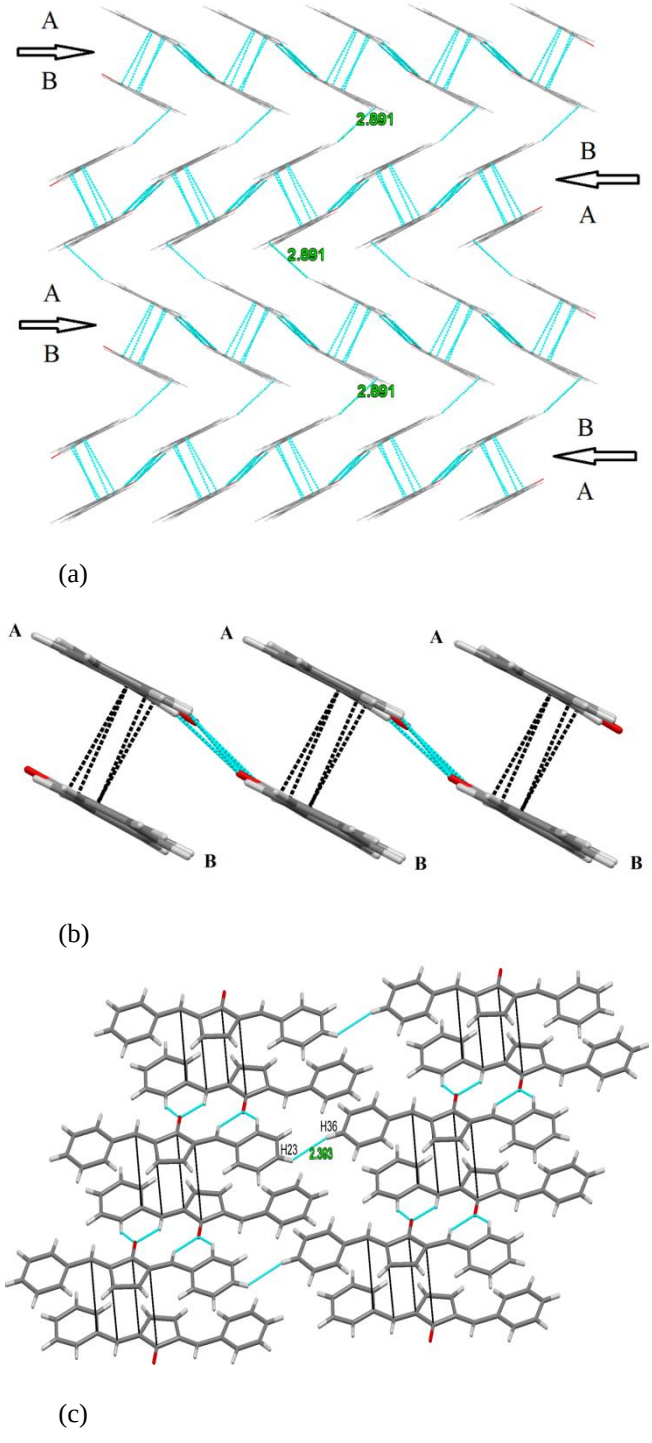


**Figure 2.** a) Sheet-like multilayered structure of polymorph (II) stabilized by C-H···O, π-π and C-H···π interactions. b) C-H···O and π-π interactions in 1D-Supramolecular chain (side view). c). Inter-chain hydrogen-hydrogen interactions between sheets forming 2D-sheet like layer.

**Table 2.** Measured and calculated bond lengths (Å).

| Bond lengths, Å | X-ray | B3LYP/6-31G | |
|---|---|---|---|
| | | Combined (A and B) | Conformer A |
| O1-C9 | 1.220 | 1.225 | 1.221 |
| C1-C2 | 1.411 | 1.410 | 1.410 |
| C1-C6 | 1.387 | 1.410 | 1.411 |
| C1-C7 | 1.471 | 1.461 | 1.461 |
| C2-C3 | 1.341 | 1.393 | 1.393 |
| C3-C4 | 1.371 | 1.397 | 1.397 |
| C4-C5 | 1.401 | 1.398 | 1.398 |
| C5-C6 | 1.391 | 1.393 | 1.393 |
| C7-C8 | 1.321 | 1.356 | 1.356 |
| C8-C9 | 1.501 | 1.506 | 1.507 |
| C8-C12 | 1.514 | 1.458 | 1.457 |
| C9-C10 | 1.471 | 1.505 | 1.500 |
| C10-C11 | 1.514 | 1.458 | 1.459 |
| C10-C13 | 1.361 | 1.356 | 1.358 |
| C11-C12 | 1.511 | 1.362 | 1.361 |
| C13-C14 | 1.451 | 1.461 | 1.461 |
| C14-C15 | 1.411 | 1.410 | 1.411 |
| C14-C19 | 1.418 | 1.411 | 1.412 |
| C15-C16 | 1.381 | 1.392 | 1.393 |
| C16-C17 | 1.411 | 1.399 | 1.398 |
| C17-C18 | 1.411 | 1.397 | 1.398 |
| C18-C19 | 1.381 | 1.393 | 1.393 |
| O2-C28 | 1.254 | 1.225 | |
| C20-C21 | 1.386 | 1.411 | |
| C20-C25 | 1.421 | 1.412 | |
| C20-C26 | 1.461 | 1.461 | |
| C21-C22 | 1.401 | 1.393 | |
| C22-C23 | 1.381 | 1.398 | |
| C23-C24 | 1.381 | 1.397 | |
| C24-C25 | 1.341 | 1.393 | |
| C26-C27 | 1.361 | 1.358 | |
| C27-C28 | 1.451 | 1.500 | |
| C27-C31 | 1.497 | 1.459 | |
| C28-C29 | 1.471 | 1.507 | |
| C29-C30 | 1.510 | 1.458 | |
| C29-C32 | 1.371 | 1.356 | |
| C30-C31 | 1.531 | 1.361 | |
| C32-C33 | 1.441 | 1.461 | |
| C33-C34 | 1.408 | 1.410 | |
| C33-C38 | 1.409 | 1.410 | |
| C34-C35 | 1.391 | 1.393 | |
| C35-C36 | 1.391 | 1.398 | |
| C36-C37 | 1.411 | 1.397 | |
| C37-C38 | 1.391 | 1.393 | |

**Geometry optimization**

The molecular conformations present in the two conformer of polymorph (II) were investigated by geometry optimization calculations using B3LYP/6-31G* basis set,[41,43] computations were carried out for conformer A & B as such and for conformer A alone, initial geometry was defined using crystallographic information. Superposed structure of the molecule over X-ray structure is shown with small conformational discrepancies between them (Figure 3). These discrepancies are originated from dihedral angles between ring planes and also because of slight difference in estimated bond angles.

The small differences between the calculated and observed geometrical parameters can be attributed to the fact that the theoretical calculations were carried out with isolated molecules in the gaseous phase whereas the experimental values were based on the molecule in the crystalline state. Geometric parameters bond lengths and angles were listed in the Table 2 and Table 3, respectively along with the experimental results. As can be seen from the table all the bond lengths are extremely closed to experimental results and the biggest deviations of the selected bond lengths are 0.17 Å (C30-C31).

**Table 3.** Optimized bond angles of conformers A & B and conformer A in comparison with experimental results, (°).

| *Bond angle (°)* | X-ray | B3LYP/6-311G | |
|---|---|---|---|
| | | Combined A&B | Conformer A |
| C1-C7-C8 | 132.5 | 130.1 | 130.4 |
| C7-C8-C9 | 119.3 | 120.7 | 120.4 |
| C7-C8-C12 | 132.5 | 133.5 | 133.9 |
| C9-C8-C12 | 108.0 | 105.6 | 105.6 |
| O1-C9-C8 | 125.6 | 126.3 | 126.7 |
| O1-C9-C10 | 126.0 | 127.0 | 126.8 |
| C8-C9-C10 | 108.3 | 106.5 | 106.4 |
| C9-C10-C11 | 109.0 | 105.5 | 105.6 |
| C9-C10-C13 | 119.5 | 121.2 | 120.4 |
| C11-C10-C13 | 131.5 | 133.2 | 133.8 |
| C10-C13-C14 | 130.7 | 129.6 | 130.4 |
| C20-C26-C27 | 132.3 | 129.5 | |
| C26-C27-C28 | 120.1 | 121.3 | |
| C26-C27-C31 | 130.9 | 133.1 | |
| C28-C27-C31 | 108.9 | 105.5 | |
| O2-C28-C27 | 126.6 | 127.1 | |
| O2-C28-C29 | 124.1 | 126.2 | |
| C27-C28-C29 | 109.3 | 106.5 | |
| C28-C29-C30 | 108.7 | 105.6 | |
| C28-C29-C32 | 120.5 | 120.7 | |
| C30-C29-C32 | 130.7 | 133.5 | |
| C29-C32-C33 | 132.0 | 130.2 | |

**Experimental and computed vibrational spectra**

It is normally observed that the calculated vibrational frequencies are higher than the normal due to the neglect of anharmonicity in the real system. Small differences between the theoretical and experimental values vibrational modes are observed. These differences can come from the non-covalent interactions. Also experimental results are for solid phase, and theoretical calculations belong to gaseous phase. Comparison of the experimental and calculated spectra is shown in Figure 4 and selected FT-IR and calculated vibrational wave numbers and assignments are listed in Table 4 for the conformer A and B considering a single molecule in a lattice.

The IR spectrum of the compound showed stretching band at 1687 cm-1 due to the carbonyl group while stretching for carbonyl groups are calculated at 1782-1784 cm-1 for the carbonyl groups of conformer A and B in a single lattice. The CH stretching modes, which were observed at 3054 and 2911 for the 5-member ring and phenyl group in the FT-IR spectrum, were calculated as 3257 and 3255 for CH stretching of cyclopentanone ring and number of stretching between 3220-3177 for the phenyl rings.

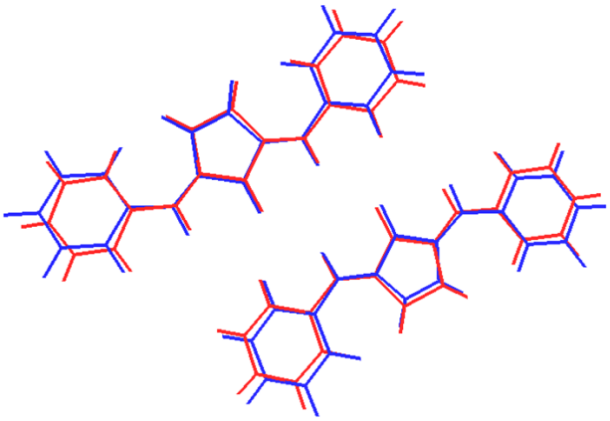

**Figure 3**. Atom-by-atom superimposition of the structures calculated (blue) on the X-ray structure (red) of polymorph (II) of DBCP.

As can be seen in table C=C (α,β-unsaturated) stretching mode, calculated as 1684-1674, were observed at 1622 in the FT-IR spectrum. These results obtained by the calculations have shown an adequate consistency with the experimental values, and small differences can be explained by the existence of intermolecular interactions like C-H…π and C-H…O.

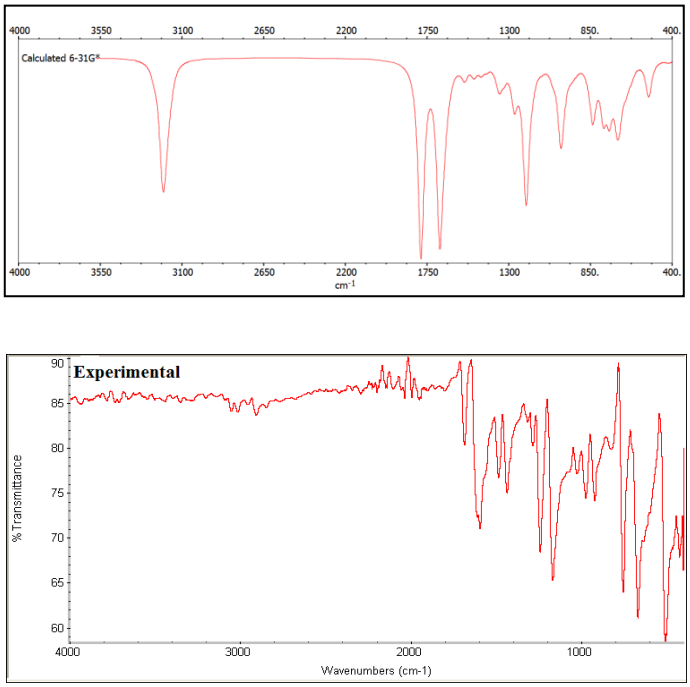


**Figure 4.** The experimental and calculated infrared spectra of the tiled compound.

**Frontier Molecular Orbitals analysis**

The most important frontier molecular orbitals (FMOs) such as highest occupied molecular orbital (HOMO) and lowest unoccupied molecular orbital (LUMO) plays a crucial part in the chemical stability of the molecule.[52] The HOMO represents the ability to donate an electron and LUMO as an electron acceptor represents the ability to accept an electron. The energy gap between HOMO and LUMO also determines the chemical reactivity, optical polarizability and chemical hardness–softness of the molecule.[53]

**Table 4.** Selected vibrational assignments ($cm^{-1}$) for polymorph (II).

| Assignment | Experimental | Calculated 6-31G* for conformer A and B |
|---|---|---|
| 5-member ring C-H str. | 3054 | 3257, 3255 |
| 5-member ring C-H asym str. | 3019 | 3240,3239 |
| phenyl rings C-H str. | 2911 | 3220-3177 |
| *α,β*-unsaturated -C=C-H str. | | 3166-3149 |
| carbonyl str. | 1687 | 1784,1782 |
| *α,β*-unsaturated C=C str. | 1622 | 1683-1674 |
| phenyl rings C=C str. | 1600 | 1626-1653 |

In the present study, the HOMO and LUMO energies are predicted at B3LYP method with 6-31G* basis set. Accordingly to the results, the molecule contains 68 occupied molecular orbitals and 240 unoccupied molecular orbitals. Figure 5 shows the distributions and energy levels of HOMO and LUMO orbitals for the title molecule in gaseous phase.

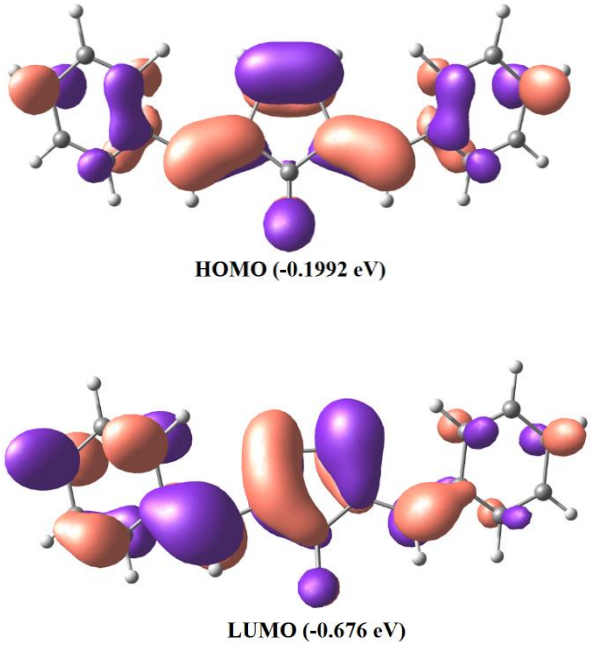


**Figure 5.** The molecular orbitals and energies for the HOMO and LUMO of 2,5-dibenzylidenecyclopentanone in gas phase.

It is clear from the Figure 5 that isodensity plot for the HOMO is well localized symmetrically over the cyclopentanone and on ipso, ortho and para position of the phenyl rings where the LUMO is populated on cyclopentanone and one of the phenyl ring along with the carbonyl group. The HOMO–LUMO energy separation can be used as a sign of kinetic stability. A large HOMO–LUMO gap implies high kinetic stability and low chemical reactivity.[54,55] As can be seen the magnitude of energy separation between HOMO and LUMO is 0.1768 eV this small gap indicates the chemical softness and high reactivity of compound.

## Conclusion

The polymorph (II) of 2,5-dibenzylidenecyclopentanone (DBCP) having two conformationally different/independent molecules in its unit cell has been obtained by slow evaporation of ethanol solvent at room temperature and further investigated by the computational calculations using B3LYP method with 6-31G* basis set to explore its structural aspects in comparison to its previously reported polymorph (I). The polymorph (II) pack in 1D-supramolecular chains mainly stabilized by C-H…O hydrogen bonds, π-π, C-H…π interactions with every two neighbouring chains moving in opposite directions. The analysis of both the experimental and calculated molecular geometries of polymorph (II) shows good agreement with each other. In addition, all the vibrational modes are closed to the observed vibrations and small energy difference between the HOMO-LUMO orbitals frontier provides significant information regarding the softness and high reactivity of the molecule.

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## References

[1]Desiraju, G. R., *Angew. Chem.-Int. Ed. Engl.*, **1995,** *34*, (21), 2311-2327.

[2]Boistelle, R., *Actual. Néphrol.,.* **1985**, 159-202.

[3]Choudhury, A. R., Islam, K., Kirchner, M. T., Mehta, G., Row, T. N. G., *J. Am. Chem. Soc.,* **2004,** *126* (39), 12274-12275.

[4]Herbstein, F. H., *Crystal Growth Design*, **2004,** *4*(6), 1419-1429.

[5]Bernstein, J., Davey, R. J., Henck, J. O., *Angew. Chem.-Int. Ed. Engl.*, **1999,** *38*(23), 3440-3461.

[6]Braga, D., Maini, L., Polito, M., Scaccianoce, L., Cojazzi, G., Grepioni, F., *Coord. Chem. Rev.*, **2001,** *216*, 225-248.

[7]Kawamura, T., Miyazaki, Y., Sorai, M., *Chem. Phys. Lett.*, **1997,** *273*(5-6), 435-438.

[8]Kalman, A., Fabian, L., Argay, G., Bernath, G., Gyarmati, Z., *J. Am. Chem. Soc.*, **2003,** *125* (1), 34-35.

[9]Matsumoto, A., Tanaka, T., Tsubouchi, T., Tashiro, K., Saragai, S., Nakamoto, S., *J. Am. Chem. Soc.*, **2002,** *124*(30), 8891-8902.

[10]McMahon, J. A., Zaworotko, M. J., Remenar, J. F., *Chem. Commun.*, **2004**(3), 278-279.

[11]Barendt, J. M., Bent, E. G., Haltiwanger, R. C., Squier, C. A., Norman, A. D., *Inorg. Chem.*, **1989,** *28*(24), 4425-4427.

[12]Reger, D. L., Gardinier, J. R., Smith, M. D., Shahin, A. M., Long, G. J., Rebbouh, L., Grandjean, F., *Inorg. Chem.*, **2005,** *44*(6), 1852-1866.

[13]Reed, S. M., Weakley, T. J., Hutchison, J. E., *Crystal Eng.*, **2000,** *3*(2), 85-99.

[14]Ballester, L., Gil, A. M., Gutierrez, A., Perpinan, M. F., Azcondo, M. T., Sanchez, A. E., Amador, U., Campo, J., Palacio, F., *Inorg. Chem.*, **1997,** *36*(23), 5291-5298.

[15]Basavoju, S., Boström, D., Velaga, S. P., *Mol. Cryst. Liq.Cryst.*, **2012,** *562*(1), 254-264.

[16]Munshi, P., Venugopala, K. N., Jayashree, B. S., Row, T. N. G., *Crystal Growth Design*, **2004,** *4*(6), 1105-1107.

[17]Davey, R. J., Blagden, N., Potts, G. D., Docherty, R., *J. Am. Chem. Soc.*, **1997,** *119*(7), 1767-1772.

[18]Sarma, B., Chen, J., Hsi, H.-Y., Myerson, A., *Korean J. Chem. Eng.*, **2011,** *28*(2), 315-322.

[19]Aakeröy, C. B., Forbes, S., Desper, J., *J. Am. Chem. Soc.*, **2009,** *131*(47), 17048-17049.

[20]Chieng, N., Rades, T., Aaltonen, J., *J. Pharm. Biomed. Anal.*, **2011,** *55*(4), 618-644.

[21]Blagden, N., De Matas, M., Gavan, P., York, P., *Adv. Drug Deliv. Rev.*, **2007,** *59*(7), 617-630.

[22]Kawamata, J., Inoue, K., Inabe, T., *Appl. Physics Lett.*, **1995,** *66*(23), 3102-3104.

[23]Kawamata, J., Inoue, K., Inabe, T., *Bull. Chem. Soc. Jap.*, **1998,** *71*(12), 2777-2786.

[24]Kawamata, J., Inoue, K., Inabe, T., Kiguchi, M., Kato, M., Taniguchi, Y., *Chem. Phys. Lett.*, **1996,** *249*(1), 29-34.

[25]Ravindra, H., Chandrashekaran, K., Harrison, W., Dharmaprakash, S., *Appl.Phys. B.* **2009,** *94*(3), 503-511.

[26]Indira, J., Karat, P. P., Sarojini, B., *J. Cryst. Growth*, **2002,** *242*(1), 209-214.

[27]Nesterov, V. V., Antipin, M. Y., Nesterov, V. N., Penn, B. G., Frazier, D. O., Timofeeva, T. V., *Crystal Growth Design*, **2004,** *4*(3), 521-531.

[28]Nesterov, V. V., Antipin, M. Y., Nesterov, V. N., Moore, C. E., Cardelino, B. H., Timofeeva, T. V., *J. Phys. Chem., B.* **2004,** *108*(25), 8531-8539.

[29]Guilford, W. J., Shaw, K. J., Dallas, J. L., Koovakkat, S., Lee, W., Liang, A., Light, D. R., McCarrick, M. A., Whitlow, M., Ye, B., *J. Med. Chem.*, **1999,** *42*(26), 5415-5425.

[30]Nesterov, V. N., Timofeeva, T. V., Sarkisov, S. S., Leyderman, A., Lee, C. Y. C., Antipin, M. Y., *Acta Cryst. Sect. C.* **2003,** *59*(11), o605-o608.

[31]March, J., *Adv. Org. Chem.*, Wiley, New York, **1992**.

[32]Katsori, A. M., Hadjipavlou-Litina, D., *Expert. Opin. Ther. Path.*, **2011,** *21*(10), 1575-96.

[33]Asiri, A. M., Khan, S. A., *Molecules.* **2011,** *16* (1), 523-31.

[34]Husain, A., Rashid, M., Mishra, R., Kumar, D., *Acta Pol. Pharm.*, **2013,** *70*(3), 443-9.

[35]Solano, J. D., Gonzalez-Sanchez, I., Cerbon, M. A., Guzman, A., Martinez-Urbina, M. A., Vilchis-Reyes, M. A., Martinez-Zuniga, E. C., Alvarado, C., Quintero, A., Diaz, E., *Eur. J. Med. Chem.*, **2013,** *60*, 350-9.

[36]Dominguez, J. N., de Dominguez, N. G., Rodrigues, J., Acosta, M. E., Caraballo, N., Leon, C., *J. Enzyme Inhib. Med. Chem.*, **2013,** *28*(6), 1267-73.

[37]Vijaya Bhaskar Reddy, M., Shen, Y. C., Ohkoshi, E., Bastow, K. F., Qian, K., Lee, K. H., Wu, T. S., *Eur. J. Med. Chem.*, **2012,** *47*(1), 97-103.

[38]Modzelewska, A., Pettit, C., Achanta, G., Davidson, N. E., Huang, P., Khan, S. R., *Bioorg. Med. Chem.*, **2006,** *14*(10), 3491-5.

[39]Theocharis, C. R., Jones, W., Thomas, J. M., Motevalli, M., Hursthouse, M. B., *J. Chem. Soc., Perkin Trans. 2.* **1984**(1), 71-76.

[40]Sheldrick, G. M., *Acta Cryst., Sect. A. Found. Cryst.*, **2007,** *64*(1), 112-122.

[41]Becke, A. D., *J. Chem. Phys.*, **1993,** *98*(7), 5648-5652.

[42]Lee, C., Yang, W., Parr, R. G., *Phys. Rev. B.*, **1988,** *37*(2), 785.

[43]Hehre, W. J., Ditchfield, R., Pople, J. A., *J. Chem. Phys.*, **1972,** *56*(5), 2257-2261.

[44]Neese, F., *Wiley Interdiscipl. Rev.: Comput. Mol. Sci.*, **2012,** *2*(1), 73-78.

[45]Allouche, A. R., *J. Comput. Chem.*, **2011,** *32*(1), 174-182.

[46]Allen, F. H., Kennard, O., Watson, D. G., Brammer, L., Orpen, A. G., Taylor, R., *J. Chem. Soc., Perkin Trans. 2.*, **1987**(12), S1-S19.

[47]Etter, M. C., *Acc. Chem. Res.*, **1990,** *23*(4), 120-126.

[48]Naseer, M. M., Hameed, S., *Crystengcomm*, **2012,** *14*(13), 4247-4250.

[49]Casadesús, R., Moreno, M., González-Lafont, à., Lluch, J. M., Repasky, M. P., *J. Comput. Chem.*, **2004,** *25*(1), 99-105.

[50]Abbas, A., Nazir, H., Naseer, M. M., Bolte, M., Hussain, S., Hafeez, N., Hasan, A., *Spectrochim. Acta. A. Mol. Biomol. Spectr.*, **2014,** *120*, 176-84.

[51]Mikhailov, O. V., Chachkov, D. V., *Eur. Chem. Bull.*, **2014,** *3*(4), 367-371.

[52]Becker, H. G. O., *J. Prakt. Chem.*, **1978,** *320*(5), 879-880.

[53]Kosar, B., Albayrak, C., *Spectrochim. Acta Part A. Mol. Biomol.r Spectr.*, **2011,** *78*(1), 160-167.

[54]Özbek, N., Kavak, G., Özcan, Y., Ide, S., Karacan, N., *J. Mol. Struct.*, **2009,** *919*(1), 154-159.

[55]Kumar, P. S., Vasudevan, K., Prakasam, A., Geetha, M., Anbarasan, P., *Spectrochim. Acta Part A. Mol. Biomol. Spectr.*, **2010,** *77*(1), 45-50.

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