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# PHOTOCHEMISTRY OF 2-(3, 4, 5-TRIMETHOXYPHENYL)-4-(3, 4-METHYLENEDIOXYPHENYL)-4-OXO-2-BUTENONITRILE (β-CYANOCHALCONE): ANOMALOUS DIMERIZATION THROUGH ISOMERIZATION IN THE SOLID STATE1)

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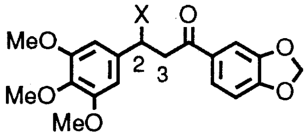
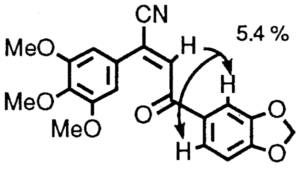
Exposure of the (*E*)-isomer (**4E**) of 2-(3, 4, 5-trimethoxyphenyl)-4-(3, 4-methylenedioxyphenyl)-4-oxo-2-butenonitrile (β-cyanochalcone) in the solid state to sunlight led to unusual dimerization through isomerization to give an unsymmetrical E-Z dimer (**7**) along with a symmetrical Z-Z dimer (**5**) obtainable from the photoreactive (Z)-isomer (**4Z-b**).

**KEYWORDS** solid state photochemistry; photoisomerization; [2+2] cycloaddition reaction; cyclobutane dimer; X-ray crystallographic analysis; β-cyanochalcone

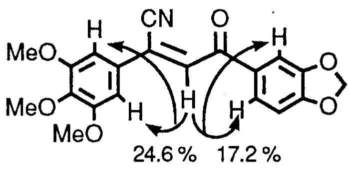
Solid state photoreactions2) of alkenic compounds including chalcone3) normally cause dimerizations most of which are strictly controlled by the topochemistry either of the bulk or the defect regions in the crystal to give a single dimer. In the course of synthesis studies on benzo[*c*]phenanthridine alkaloids showing antitumor activity, we occasionally found that the (*E*)-isomer (**4E**) of 2-(3, 4, 5-trimethoxyphenyl)-4-(3, 4-methylenedioxyphenyl)-4-oxo-2-butenonitrile (β-cyanochalcone), prepared for mechanistic consideration on formation of the unsaturated acid (**2**) in alkaline hydrolysis4) of the amide (**1**), isomerized in the solid state to yield unexpected dimers (**5** and **7**) when exposed to sunlight. Here we present the anomalous photobehavior of **4E** in addition to the predictable photoreaction of the (Z)-isomer (**4Z**).



**1** : X=CONH$_2$
**2** : X=CO$_2$H, 2,3-dehydro
**3** : X=CN



**4E**

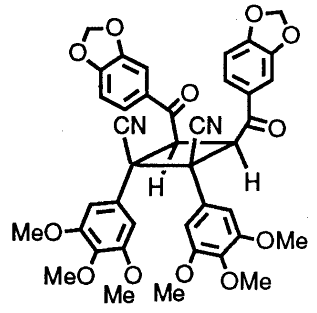


**4Z (4Z-a, 4Z-b)**

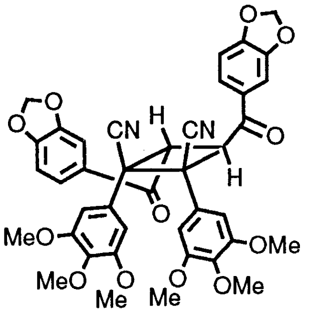
Dehydrogenation of the saturated nitrile5) (**3**) with 2, 3-dichloro-5, 6-dicyano-1, 4-benzoquinone (DDQ) in the dark provided the unsaturated nitriles6) (**4E** and **4Z**) in 40.2 % and 44.4 % yields, respectively. The stereochemistry of each nitrile was confirmed by difference NOE experiments in their $^1$H-NMR spectra. In the (*E*)-isomer (**4E**) irradiation of the signal at δ 5.55, due to an olefinic proton, enhanced the integrals of both aromatic protons at ortho positions in the methylenedioxybenzoyl group. But in the (Z)-isomer (**4Z**), an additional NOE enhancement appeared between the aromatic protons in the trimethoxyphenyl group and an olefinic proton.

The (Z)-isomer (**4Z**) was crystallized into dimorphic forms [**4Z-a**: yellow fine prisms (from benzene-hexane), mp 153-156 °C; **4Z-b**: yellow fine needles (from benzene or ethanol), mp 168-169.5 °C]. Though the crystal (**4Z-a**) with a lower melting point was found to be quite stable to light, the other crystal (**4Z-b**) smoothly underwent solid state photoreaction to yield colorless needles (**5**), mp 169-170 °C7), as a single product in 65.0 % yield. Easy thermal regeneration8) of **4Z** from **5** suggested that **5** was a symmetrical cyclobutane dimer derived from **4Z**. This was supported by its $^1$H-NMR spectrum showing only one singlet at δ 4.89 due to a newly born methine proton in place of the disappearance of an olefinic proton. The mirror symmetry structure of **5** was established by X-ray crystallographic analysis9) showing that the starting **4Z-b**11) crystallizes in the β-modification responsible for topochemical translation to a mirror symmetry dimer such as β-truxinic acid (**6**).12)

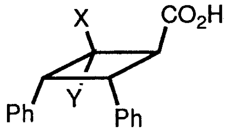
Exposure of the (*E*)-isomer (**4E**), yellow fine needles, mp 112-114 °C, to sunlight or Daylight lamp®13) for 37.5 h afforded two dimers along with the starting **4E** (33.7 %) and the isomerized **4Z** (27.7 %) monomers. One of the dimers yielded in 11.0 % was identified as the same symmetrical dimer (**5**) that was derived from the photoreactive (Z)-isomer



5



7

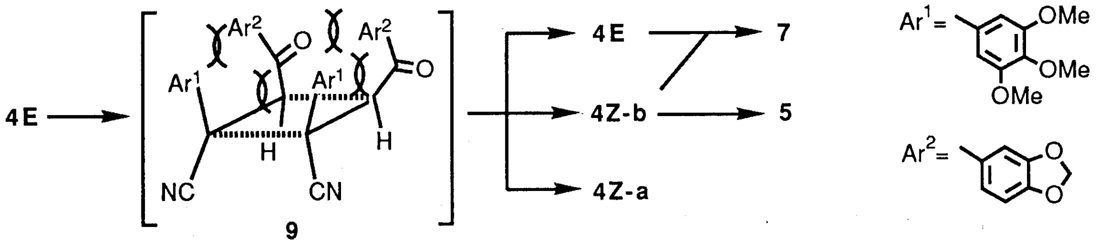


**6** : X=$CO_2H$, Y=H

**8** : X=H, Y=$CO_2H$

(**4Z-b**). The second dimer (**7**) was given as colorless fine needles, mp 117-120°C, in 14.6 % yield. Thermal generation[8] of the isomeric monomers (**4E** and **4Z**) from this dimer (**7**) and isomerization of the symmetrical dimer (**5**) to the alternative dimer (**7**) by silica gel suggested that **7** belonged to an unsymmetrical E-Z dimer with the configuration of *neo*-truxinic acid (**8**).[14] The $^1$H-NMR spectrum showed coupled 1H doublets ($J$=10.5 Hz) at $\delta$ 5.34 and $\delta$ 5.44 attributable to newly born methine protons. NOE enhancements appeared between the methine proton at $\delta$ 5.34 and four aromatic protons at ortho positions of two trimethoxyphenyl rings. This allowed us to depict a chiral structure shown as **7** for the second dimer. The correctness of the structure was unambiguously confirmed by X-ray crystallographic analysis.[15] Thus sunlight irradiation to **4E** in the solid state preferentially induced isomerization followed by dimerization, and the formation of the dimers (**5** and **7**) suggested that the starting **4E**[11] also crystallized in β-modification.

Solid state photoisomerization of alkenic compounds is not so common as dimerization. Schmidt and co-workers[16] interpreted the photoreactions of *cis*-cinnamic acids yielding the *trans* isomers and/or dimers as lattice-controlled isomerization which is exerted through a metastable complex formed between the excited molecule and its closest neighbor. Recently an Indian group[17] reinvestigated the solid state cycloaddition reaction of (*E*)-β-nitrostyrene giving an unusual E-Z dimer like **7** and accounted for the dimerization by the disordered crystal structure of the starting nitrostyrene permitting isomerization. Unfortunately precise discussion on the solid state photochemistry[18] of **4E** has failed because of lack of the crystal data of **4E**, but three-dimensional studies of the supposed metastable complex[16] (**9**) using a Dreiding model shows that direct [2+2] cycloaddition from the complex (**9**) would be impossible due to a severe steric repulsion by the *cis* arrangement of all of the trimethoxyphenyl and the methylenedioxybenzoyl substituents in a formed dimer, even if the dimerization is topochemically favored. Thus in our case the steric restriction effect may also trigger generation of possible monomers (**4E**, **4Z-a**, and **4Z-b**) with partial isomerization, the photoreactive (*Z*)-isomer (**4Z-b**) among which could react with either another **4Z-b** or **4E** to produce the [2+2] cycloadducts (**5** and **7**).



As a comparable experiment we examined the photochemistry in solution. Exporsure of each isomer (**4E** and **4Z**) to light in solution led to quantitative isolation of **4E** indicating that photosensitive **4E** in solid state exsisted as a photostable isomer in solution.

For detailed knowledge further examination of the photochemistry of some β-substituted chalcones including the β-cyanochalcone (**4**) is now in progress.

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6) All new compounds except **5** described in this paper provided satisfactory analytical and spectroscopic data.
7) TLC of **5** after metling showed only one spot corresponded to the spot of **4Z**. Thus the observed melting point would be attributed to the starting **4Z-b**.
8) Heating a solution of a dimer in ethyl acetate completely gave the corresponding monomer(s).
9) Crystal data for **5**: $C_{40}H_{34}N_2O_{12}\ C_3H_6O$, M=792.77, monoclinic, space group $P2_1/n$ with unit cell dimensions a=19.076(7), b=15.176(1), c=13.999(5) Å, β=102.64(4)°, $U$=3954.73 Å$^3$, $Z$=4, and $D_c$=1.332 g/cm$^3$. The reflection data were collected on a Rigaku AFC-5 diffractometer for $3° < 2\theta < 120°$ using Cu$K\alpha$ radiation ($\lambda$=1.54178 Å) and the $\omega < 30° < \omega\text{-}2\theta$ scan method at a $2\theta$ scan speed of 4°/min. The structure was solved by the direct method using the MULTAN (UNICS-III system[10)]) program and refined by full-matrix least-squares. The final $R$ value was 0.0606 for 4279 independent reflections [$F_o > 3\sigma(F_o)$].
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11) Trials to prepare a single crystal for X-ray analysis have not been successful.
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15) Crystal data for **7**: $C_{40}H_{34}N_2O_{12}\ 2(C_3H_6O)$, M=850.84, triclinic, space group $P_1$ with unit cell dimensions a=12.155(4), b=16.978(4), c=11.612(9) Å, α=107.95(4)°, β=105.25(4)°, γ=78.77(1)°, $U$=2182.785 Å$^3$, $Z$=2, and $D_c$=1.118 g/cm$^3$. The reflection data were collected on a Rigaku AFC-5 diffractometer for $3° < 2\theta < 120°$ using Cu$K\alpha$ radiation ($\lambda$=1.54178 Å) and the $\omega < 30° < \omega\text{-}2\theta$ scan method at a $2\theta$ scan speed of 4°/min. The structure was solved by the direct method using the MULTAN (UNICS-III system[10)]) program and refined by full-matrix least-squares. The final $R$ value was 0.1622 for 3928 independent reflections [$F_o > 3\sigma(F_o)$]. The crystal contains acetone with a high thermal factor, especially on the oxygen atom (B=*ca.* 16), as a crystal solvent. This may cause the unsatisfactory refinement.
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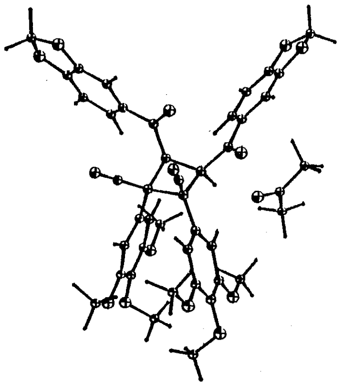
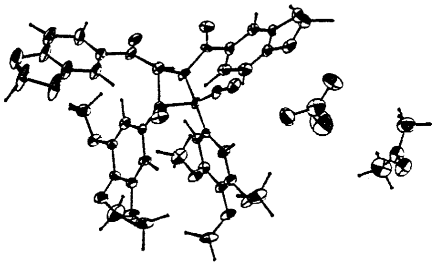
17) G. R. Desiraju and V. R. Pedireddi, *J. Chem. Soc., Chem. Commun.*, **1989**, 1112.
18) Trace of the photoreaction by powdered X-ray diffraction resulted in observation of only peak broadenings.



ORTEP drawing of **5**



ORTEP drawing of **7**

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