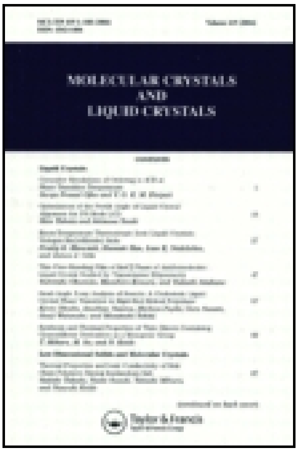
This article was downloaded by: [Tomsk State University of Control Systems and Radio]
On: 19 February 2013, At: 11:20
Publisher: Taylor & Francis
Informa Ltd Registered in England and Wales Registered Number: 1072954 Registered office: Mortimer House, 37-41 Mortimer Street, London W1T 3JH, UK



Molecular Crystals and Liquid Crystals Incorporating Nonlinear Optics
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/gmcl17

Selective Reactions in the Solid State and Organic Solid-Solid Reactions

Fumio Toda [a]
[a] Department of Industrial Chemistry, Faculty of Engineering, Ehime University, Matsuyama, 790, Japan

Version of record first published: 22 Sep 2006.

To cite this article: Fumio Toda (1990): Selective Reactions in the Solid State and Organic Solid-Solid Reactions, Molecular Crystals and Liquid Crystals Incorporating Nonlinear Optics, 187:1, 41-48

To link to this article: http://dx.doi.org/10.1080/00268949008036025

PLEASE SCROLL DOWN FOR ARTICLE

Full terms and conditions of use: http://www.tandfonline.com/page/terms-and-conditions

This article may be used for research, teaching, and private study purposes. Any substantial or systematic reproduction, redistribution, reselling, loan, sub-licensing, systematic supply, or distribution in any form to anyone is expressly forbidden.

The publisher does not give any warranty express or implied or make any representation that the contents will be complete or accurate or up to date. The accuracy of any instructions, formulae, and drug doses should be independently verified with primary sources. The publisher shall not be liable for any loss, actions, claims, proceedings, demand, or costs or damages whatsoever or howsoever caused arising directly or indirectly in connection with or arising out of the use of this material.

Mol. Cryst. Liq. Cryst., 1990, vol. 187, pp. 41–48
Reprints available directly from the publisher
Photocopying permitted by license only
© 1990 Gordon and Breach Science Publishers S.A.
Printed in the United States of America

SELECTIVE REACTIONS IN THE SOLID STATE AND ORGANIC SOLID-SOLID REACTIONS

FUMIO TODA
Department of Industrial Chemistry, Faculty of
Engineering, Ehime University, Matsuyama 790, Japan

Abstract Since guest molecules in a host-guest complex are arranged regularly and are packed closely, reaction of the guest in the complex is expected to proceed selectively and efficiently in the solid state. When the host compound is chiral, reaction of the guest would proceed enantioselectively. Some such reactions were studied. Furthermore, some usual organic reactions were found to proceed in the solid state. In some cases, organic solid state reactions proceeded more selectively and much faster than in solution. Such solid-solid reactions were also investigated.

Downloaded by [Tomsk State University of Control Systems and Radio] at 11:20 19 February 2013

INTRODUCTION

It is one of the most important subjects for organic chemists to find efficient and selective synthetic methods of materials. Since molecules are arranged regularly in crystals, reaction in the crystal is expected to proceed regularly. We adopted host-guest inclusion complexes in order to arrange molecules regularly in crystals. This method is very useful to control the arrangement of guest molecules in crystals. For example, when a host molecule includes one guest molecule to form a 1:1 complex, an intramolecular reaction of the guest is expected in the complex. When a host molecule includes two guest molecules in close positions, an intermolecular reaction of the guests is expected in the complex. In these cases, enantioselective reactions are expected when a chiral host molecule is used. Furthermore, efficient high concentration reactions are expected for solid-solid organic reactions in crystals, since crystals are simple examples of molecular assembly.

Downloaded by [Tomsk State University of Control Systems and Radio] at 11:20 19 February 2013

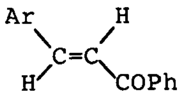
We found many solid-solid organic reactions which proceed efficiently and much faster than in solution.

Stereoselective Photoreaction in Host-Guest Complex

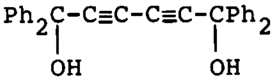
The photodimerization of chalcone (**1a**) is not easy both in solution and in the solid state. For example, irradiation of **1a** in solution gives a mixture of **1a** and its cis isomer and/or polymer. Irradiation of **1a** in the solid state results in a complex mixture of all possible stereoisomeric photodimers in low yield. X-Ray crystal structural studies of two dimorphs of **1a** show that the distance between the double bond centers are 5.2 Å in one dimorph and greater than 4.8 Å in another dimorph although the molecules are packed in a parallel manner in both cases. Those distances are longer than the limit for an intermolecular reaction (4.2 Å, Schmidt rule) and therefore the two dimorphs are photoinactive.

Contrarily, irradiation for 6 h in the solid state of a 1:2 inclusion compound of **2** and **1a** gave the syn-head-to-tail dimer **3a** selectively in 90% yield. Similar irradiation of the 1:2 inclusion compounds of **2** and **1b-d** gave **3b-d** in 85, 88, and 82% yields, respectively.

In order to clarify the reason of the efficient photoreaction, we made an X-ray structural study of the 1:2 complex of **2** and **1a** (Figs. 1 and 2). It is obvious that hydrogen bonding between the hydroxyl groups of **2** and the carbonyl group of **1a** plays an important role in packing 1a close together in the complex (Fig. 1). The double bonds are parallel and the distance between two of them is short enough (3.862 Å) to react easily. This arrangement of **1a** molecules enables the photodimerization to give the syn-head-to-tail product **3a**, but not the other isomer.



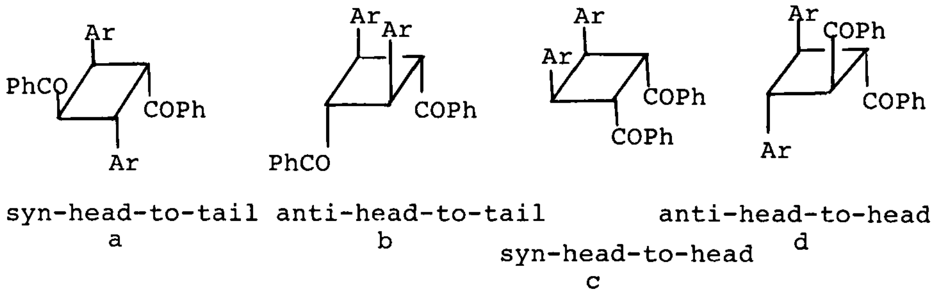
1



$Ph_2C(OH)-C\equiv C-C\equiv C-C(OH)Ph_2$

2

a: Ar=Ph
b: Ar=o-Me-C_6H_4-
c: Ar=o-MeO-C_6H_4-
d: Ar=2-Naphthyl



syn-head-to-tail
a

anti-head-to-tail
b

syn-head-to-head
c

anti-head-to-head
d

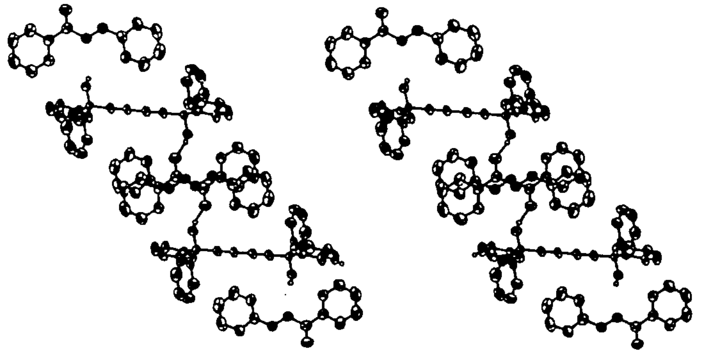


Fig. 1. Stereoscopic view of the two reacting molecules of **1a** in the crystalline host-guest complex with **2**

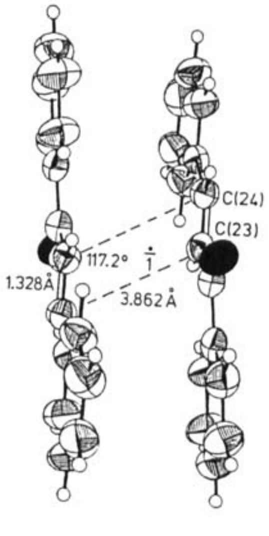
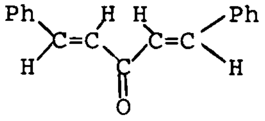
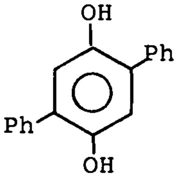


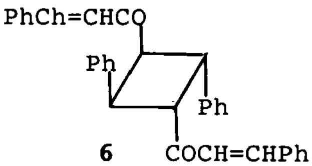
Fig. 2. Mutual relation and geometrical parameters of the reacting centers of the pair of guest molecules **1a**



4



5



6

Photodimerization of benzylideneacetone (**4**) is also very difficult both in solution and in the solid state. However, when a 1:2 complex of **4** and **5** is irradiated in the solid

Downloaded by [Tomsk State University of Control Systems and Radio] at 11:20 19 February 2013

Downloaded by [Tomsk State University of Control Systems and Radio] at 11:20 19 February 2013

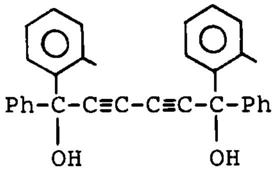
state, syn-head-to-tail dimer (**6**) was obtained in 70% yield. X-Ray crystal structural study of the complex showed that hydrogen bonding between **4** and **5** makes the packing tight and the distance between the double bonds of **4** shorten (3.787 Å). It is also clear that the arrangement of **4** in the complex can give the syn-head-to-tail product (**6**) only by the photodimerization reaction.

In a similar way, efficient and stereoselective photodimerizations of 9-formyl- and 9-acetylanthracenes and pyridones have been achieved.

ENANTIOSELECTIVE PHOTOREACTION IN HOST-GUEST COMPLEX

An enantioselective photoreaction of a guest compound is expected when an inclusion complex of the guest with an optically active host compound is irradiated in the solid state.

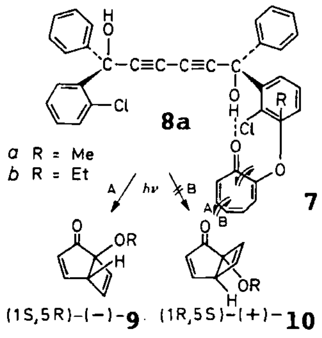
Irradiation of the powdered 1:1 inclusion compound of 2-methyltropolone (**7**) and (R,R)-(-)-1,6-di(o-chlorophenyl)-1,6-diphenylhexa-2,4-diyne-1,6-diol (**8a**) by a high-pressure Hg-lamp at room temperature for 72 h gave (1S,5R)-(-)-1-methoxybicyclo[3.2.0]hepta-3,6-dien-2-one (**9a**) of 100% ee in 11% yield together with (S)-(+)-methyl 4-oxocyclopent-2-ene acetate of 91% ee (26% yield). The latter is produced by a hydrolysis of the former. Similar irradiation of a 1:1 complex of **7b** and **8a** gave (1S,5R)-(-)-**9b** of 100% ee (12% yield) and (S)-(+)-ethyl 4-oxocyclopent-2-ene acetate of 72% ee (14% yield).


$Ph-C(C_6H_4Cl)(OH)-C\equiv C-C\equiv C-C(C_6H_4Cl)(OH)-Ph$

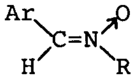
8

a: (R,R)-(-)-form

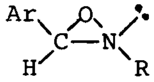
b: (S,S)-(+)-form



Although optically active oxaziridines are useful compounds for synthesis of various bioactive materials, no efficient preparative method has yet been established. We found that irradiation of an inclusion complex of nitrones **(11)** with **8a** in the solid state gives optically active oxaziridine **(12)** of high optical purity in good yield (Table 1). The reason for the efficient enatioselective reaction has also been clarified by X-ray crystal structural study of the complex.

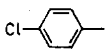
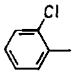
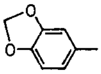
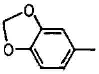


11



12

Table 1. Inclusion complexes of **11** and **8a**, their photoreactions, and photoproducts **12**

	Inclusion complex			Irradiation time (h)	Product			
	Ar	R	mp (°C)		Yield (%)	$[\alpha]_D$ (°)		% ee[a]
a	Ph	iPr	124–126	24	56	+40.7	(0.31)	—
b	Ph	tBu	135–136	36	41	+8.2	(0.55)	9.5
c		tBu	112–115	32	74	+16.0	(0.61)	30
d		tBu	108–110	12	51	−4.3	(0.83)	100
e		iPr	95–103	16	63	+20.0	(0.83)	28
f		tBu	104–111	21	52	+78.5	(0.38)	94
g	Ph	iPrMeCH	126–128	24	40	+53.9	(0.50)	100

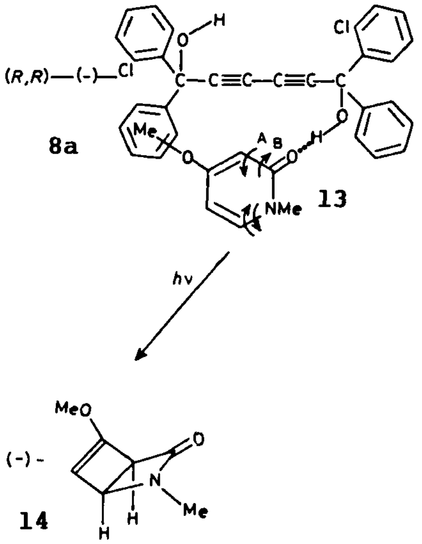
a: ee = enantiomeric excess

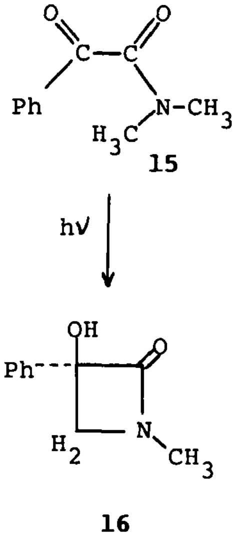
Development of new enantioselective synthetic methods for β-lactam derivatives is an attractive subject for organic chemists. We searched for such new methods, and found that irradiation of pyridone inclusion complex with **8a** in the solid state gives optically active β-lactam. For example, irradiation of the 1:1 complex of **8a** and 4-methoxy-1-methylpyridone **(13)** in the solid state gave (−)-5-methoxy-2-methyl-2-azabicycl[2.2.0]hex-5-en-3-one **(14)** of 100% ee. The mechanism of the enantioselective photoreaction of **13**

Downloaded by [Tomsk State University of Control Systems and Radio] at 11:20 19 February 2013

Downloaded by [Tomsk State University of Control Systems and Radio] at 11:20 19 February 2013

in the complex was investigated by means of an X-ray crystal structural determination. Although two directions (A and B) are possible in the photochemical disrotatory ring closure of **13** to **14**, the steric constraints allow cyclization only in the A direction, and this should produce **14** of (S,S) configuration.





Irradiation of the 1:1 inclusion complex of **8a** and oxoamide (**15**) in the solid state gave optically pure β-lactam derivative (**16**).

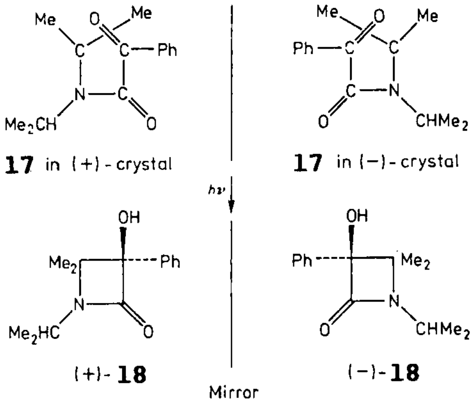
The most exciting enantioselective photochemical conversion of an α-oxoamide to a β-lactam has been found in the case of N,N-diisopropylbenzoylformamide (**17**) which gives β-lactam **18**. Recrystallization of **17** from benzene afforded colorless prisms. That each crystal is chiral was shown by photochemical conversion into optically active **18**. Crystals of **17** which gave (+)- and (-)-**18** on photocyclization have been tentatively identified as (+)- and (-)-crystals of **17**, respectively. Large amounts of the (+)- and (-)-crystals of **17** can easily be prepared by seeding with finely powdered (+)- and (-)-crystals, respectively, during recrystallization of **17**. Seeding with (-)-crystals during recrystallization of (+)-crystals gives (-)-crystals and vice versa.

Downloaded by [Tomsk State University of Control Systems and Radio] at 11:20 19 February 2013

Irradiation of (+)-crystals of **17** with a 400W high-pressure Hg-lamp, with occasional grinding with an agate mortar and pestle, for 40 h at room temperature gave (+)-**18** of 93% ee in 75% yield. Purification to 100% ee can easily be achieved by recrystallization from benzene. Although the photochemical conversion of **17** into **18** on irradiation in the solid state has been reported, enantioselectivity of the reaction has not been discussed.

X-Ray crystal structural analysis of a (+)-crystal of **17** shows that molecules of **17** are arranged so as to be chiral in the crystalline lattice.

The present data may throw some light on the generation of optically active amino acids on the earth. Photocyclization of **17** efficiently in sunlight in the solid state and hydrolysis of the optically active **18** gives an optically active β-amino acid.



ORGANIC SOLID-SOLID REACTIONS

Pinacol rearrangement of α-glycols was found to proceed efficiently in the solid state in the presence of solid acids such as p-toluenesulfonic or trichloroacetic acid and of gaseous acid such as hydrogen chloride. When the rearrangement of α-glycol was carried out in the inclusion complex with a host compound, selective reaction occurred.

Surprisingly, it was found that Baeyer-Villiger reaction proceeds much faster in the solid state than in solution.

Reduction of ketones with $NaBH_4$ also proceeded in the solid state efficiently. When inclusion compounds of ketones with optically active hosts such as **8** is treated with borane ethylenediamine complex ($2BH_3 \cdot H_2NCH_2CH_2NH_2$) in the solid state, enantioselective reaction occurred and optically active alcohol is obtained.

Coupling reaction of phenols by $FeCl_3$ and Grignard reactions are also able to be carried out in the solid state. In some cases, reaction in the solid state is more efficient and selective than in solution.

These solid-solid reactions are accelerated by irradiation with ultrasound or by shaking or grinding.

In the future, those reactions which can be carried out without using solvent would become very important due to various reasons such as efficiency, pollution control, economics, etc.

Downloaded by [Tomsk State University of Control Systems and Radio] at 11:20 19 February 2013