THERMAL REARRANGEMENT OF PHENYL-SUBSTITUTED KETENE

ETHYLENE ACETALS

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Abstract – Thermal rearrangement of mono-, di-, and triphenyl-substituted

ketene ethylene acetals was studied. Pyrolysis of all of these acetals provided

phenyl-substituted tetrahydro-2-furanones as a major product. The more phenyl

groups substitute on the ketene acetal skeleton, the lower reaction temperature

was required for the rearrangement. In the cases of the diphenylketene acetals at

high temperatures, fragmentation products, such as fluorene and benzophenone,

probably derived from dipheylcarbene *via* diphenylketene, were observed.

INTRODUCTION

Skeletal rearrangement of organic molecules in a thermal reaction is a useful tool in organic synthesis.

Involvement of an unexpected skeletal reorganization has attracted organic chemists in respect to not only

its synthetic applications but also mechanistic studies.[1] We reported that the pyrolysis of ethylene acetal

of bicyclo[4.2.0]octa-4,7-diene (**1**) at 400 ˚C provided 3-(2-hydroxyphenyl)tetrahydro-2-furanone (**2**) and

proposed the reaction mechanism outlined in Scheme 1.[2] It is important to note that the last step of this

mechanism includes the thermal functional group transformation of a ketene ethylene acetal into a

tetrahydro-2-furanone. In respect to the relevant roles of tetrahydro-2-furanones in organic chemistry[3~5]

and biochemistry,[5] we have pursued the synthetic potentiality of this transformation in a thermal reaction.

In this paper, we describe that such thermal skeletal rearrangement indeed occurred in three simple phenyl-substituted ketene ethylene acetals; also, in thermolysis of diphenylketene acetals at high temperatures, fragmentation products were observed.
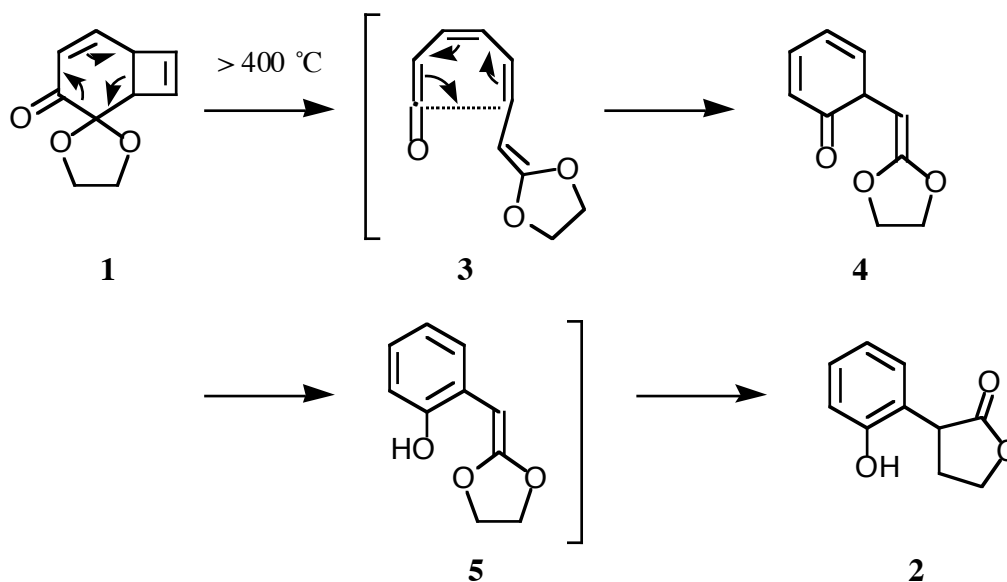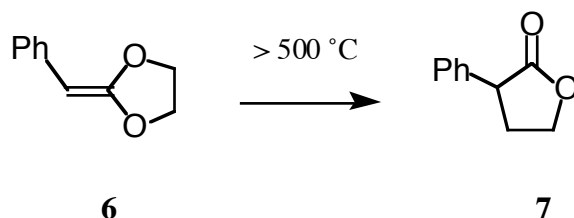

Scheme 1

RESULTS AND DISCUSSION

Thermal reactions were carried out by passing a benzene solution of an acetal through a hot quartz tube under a nitrogen stream and the pyrolysate was collected by a cold trap. Rearrangement of phenylketene ethylene acetal (**6**)[6] was observed at above 500 °C to give 3-phenyltetrahydro-2-furanone (**7**)[7] (Scheme 2). The only product observed was **7**, though the yield was low (Table 1). The phenyl substitution is indispensable for this transformation, because pyrolysis of non-substituted ketene ethylene acetal[8] under the same conditions did not give any rearranged product. Baldwin *et al*. had reported that **6** did not isomerize under photochemical conditions and rather gave the trimer.[6] Thus, this thermolytic method for **6** provides a new synthetic access to this transformation. On the other hand, diphenylketene ethylene acetal (**8**)[9] underwent rearrangement at lower temperatures compared with **6** (Scheme 3, Table 2); 3,3-diphenyltetrahydro-2-furanone (**9**) was obtained at above 400 °C along with vinyl diphenylacetate (**10**),[10] benzophenone (**11**) and fluorene (**12**), though **8** was recovered at 300 °C without any clear products. Further substitution of a phenyl group at the ethylene acetal ring makes the rearrangement more efficient; dipehylketene phenylethylene acetal (**13**)[11] rearranged at below 400 °C with less amounts of the by-

products which include **11**, **12** and also phenyloxirane (**15**) (Scheme 4, Table 2). The reaction of **13** provided 3,3,4-triphenyltetrahydro-2-furanone (**14**)[11] as a major product and isomeric 3,3,5-triphenyltetrahydro-2-furanone was not observed. Thus, the rearrangement proceeds regioselectively.
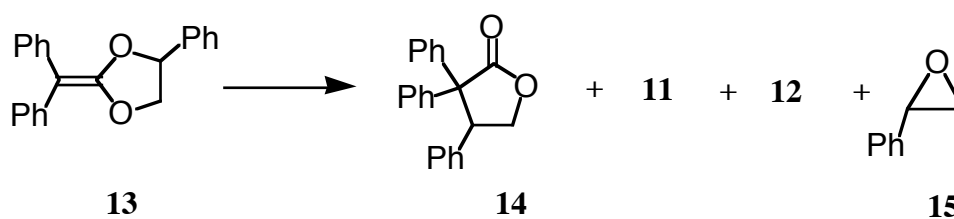

Scheme 2

Table 1. The thermal rearrangement of **6**.

entry	temeprature	yield (%) of **7**	conversion (%)
1	750 °C	16	100
2	700 °C	19	100
3	600 °C	10	74
4	500 °C	6	40
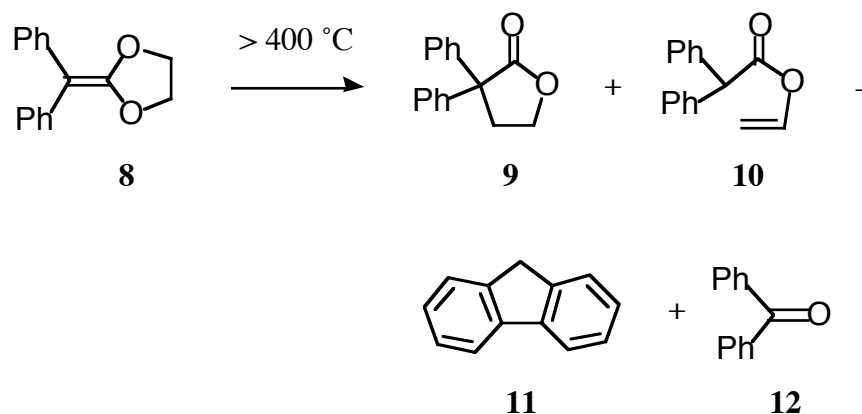
Scheme 3

Scheme 4

Table 2. The thermal rearrangement of **8** and **13**.

entry	substrate	temp. (°C)	yield (%) of products						conversion (%)
			9	**14**	**10**	**11**	**12**	**15**	
1	**8**	600	20	−	8	27	8	–	100
2	**8**	500	27	−	10	22	7	–	100
3	**8**	400	22	−	8	15	6	–	93
4	**13**	350	–	29	–	8	9	14	100
5	**13**	300	–	56	–	4	8	9	94
6	**13**	250	–	38	–	0	0	2	72

It is now clear that thermal rearrangement of phenyl-substituted ketene ethylene acetals into tetrahydro-2-furanone, formally a 1,3-shift, proceeds as a major reaction path. The thermal 1,3-shift of alkyl groups in 1-alkoxy-1-phenylethenes was reported as a process through radical intermediates.[12] The mechanism of this shift in the alkoxyphenylethenes was evidenced by the facts of the cross alkyl migration between two different alkoxyphenylethenes[13] and a capture of the hydrocarbon solvent used by the intermediate radicals.[14] The skew structures of the ethylene acetal ring in **6** and **8** optimized by density functional calculations at the BLYP/6-31G* level of theory are hard to adopt folded transition state structures for a concerted 1,3-shift, which is not allowed by the Woodward-Hoffmann rule;[15] average torsion angles of the CH_2–O–C=C part in the structures are 14.9 and 15.4°, respectively.[16] Therefore, the diradical intermediates, **16**, **17** and **18**, for the transformation of **6**, **8** and **13** into **7**, **9** and **14**, respectively, are the most plausible.[17] A hydrogen shift of the ethylene chain to the radical oxygen center in **16** accounts for the formation of **10**, though the reason for the limited formation of vinyl ester in this series of reactions is not clear yet. The oxygen radical in **16**-**18** can be stabilized by the phenyl group through the central carbon-carbon double bond and the carbon radical in **18** also directly by the phenyl group attached at the carbon. Thus, the relative thermal reactivity for **6**, **8** and **13** may be rationalized by the order of the relative stability of the diradical intermediates, which is estimated simply by the number of the phenyl substitution; *id est*, the more phenyl groups substitute on the ketene acetal skeleton, the greater stability should be gained in their intermediates. The selective C–O bond cleavage at the carbon attached by a

phenyl group in the ethylene acetal ring of **13**, being responsible for the regioselectivity, may also be due to the same stabilization.
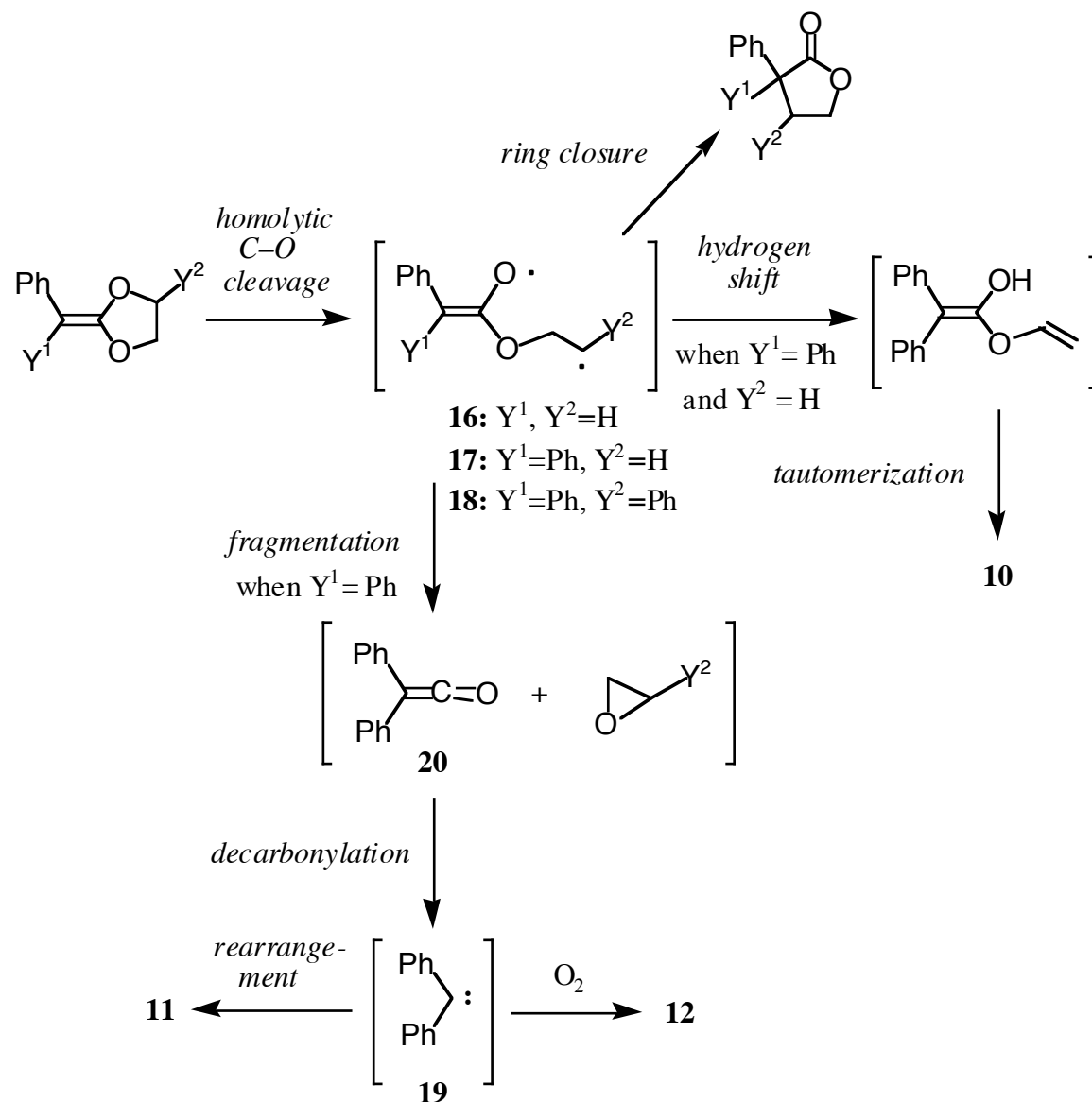
Scheme 5. Possible reaction mechanism for the thermal reactions of ketene ethylene acetals

In the thermal reactions of **8** and **13**, **11** and **12** were obtained as by-products. Both **11** and **12** are known to be formed from diphenylcarbene (**19**) *via* oxidation and rearrangement, respectively;[18] **19** generated in an oxygen-doped matrix was reported to produce (**12**)[19] and pyrolytic generation of **19** at above 400 °C resulted in formation of **11**.[20,21] Particularly, it should be noted that pyrolysis of diphenylketene (**20**) itself at above 500 °C was proposed to provide carbon monoxide and **11** through **19** by Staudinger.[22] Although we do not have clear evidence for the formation of **19**, the greater yield of **11** at the higher temperature

and the fact that the nitrogen gas used for the flow contains a trace amount of oxygen (less than 10 ppm) would suggest formation of **11** and **12** from **19**. There can be two possible paths to **19** from **8** and **13**; one is a fragmentation reaction forming **19** along with ethene and carbon dioxide (Scheme 6) and the other is the reaction forming oxirane or **15**, **19** and carbon monoxide, the latter two of which are formed through **20**. Although we could detect neither oxirane nor ethylene in the thermolysis of **8**, the existence of **15** and no detection of phenylethene in the thermolysis of **13** support the second path. This fragmentation path is exactly reverse to its synthetic route to **13** from **15** and **20**.[11]

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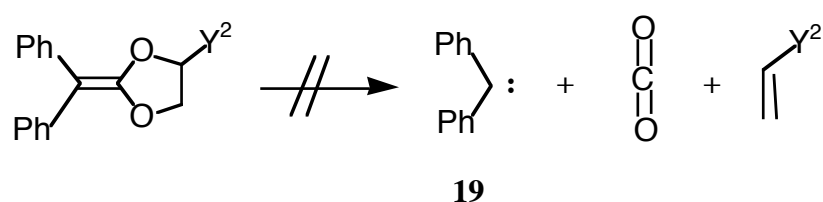
Scheme 6

EXPERIMENTAL

Materials: All starting materials and products were reported in the literature. Phenyl substituted ketene ethylene acetals (**6**,[4] **8**,[6] and **13**[8]) were prepared by the literature methods. We obtained **13** as colorless prisms with a melting point of 148-150 °C, though it was reported to be a colorless oil.[8] These materials were purified by either distillation, recrystallization or alumina chromatography before pyrolysis. Compound (**7**) was prepared by the method of Holland *et al.*[7e] Compound **9** was purchased from Aldrich Co. Compounds (**10**) and (**14**[8]) were synthesized by the literature methods. Fluorene, benzophenone and phenyloxirane were purchased from Tokyo Kasei Kogyo, Inc.

Thermal reactions of ketene ethylene acetals: A quartz tube 50 cm long and 1.7 cm in inner diameter was vertically equipped with a pressure-equalized dropping funnel at the top and a trap at the bottom. Quartz chips were stuffed in the middle part of the tube 20 cm long. This part was externally heated by an electric tube furnace. Nitrogen gas was flowed from the top of the dropping funnel through the apparatus and its flow rate was monitored at the exit of the trap. The gas flow was regulated at 240 mL/min. A benzene solution (20 mL) of the substrate (0.5 mM) charged in the funnel was dropped into the hot zone

and collected at the trap cooled at –100 ˚C. Some amounts of tar, which are insoluble in organic solvents, were found on the quartz chips. The pyrolysate was diluted with benzene and washed with a potassium carbonate solution, and was dried with anhydrous $MgSO_4$. A volume of this benzene solution was made up to 50 mL and was analyzed quantitatively by a gas chromatography apparatus (Shimadzu GC-14B) using DB-1 capillary column (Shimadzu GLC Science Ltd.).

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16. Density functional calculations were carried out with an IBM RS/6000-397 computer by using the MULLIKEN program (ver. 2.0.0, 1995, IBM Inc.). Total energies and dipole moments of **6** and **8** are –537.293770 and –768.237628 a.u., and 4.01 and 3.78 Debye, respectively.

17. Independent pyrolysis of **9** under the same conditions to those of **8** provided a recovery of **9** without any clear product. Thus, the ring closure step from the diradical intermediate is irreversible under the conditions.

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