Diepoxy[15]annulenones undergo Photochemical Carbonyl-O/Divinyl ether-O Transportation Rearrangements: Mechanistic Probing of the Rearrangement Sequences Facilitated by $^{13}C/^{17}O$ NMR Spectroscopy

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On irradiation, diepoxy[15]annulenone **1** and monobromo-diepoxy[15]annulenone **2** undergo an intriguing rearrangement, whereby all of the ether and carbonyl oxygens of **1** and **2** can travel freely and change their positions in the rings to give 15 position isomers in all.

Traditionally annulene bridges are reported to be in fixed positions,[1] but, this is not the case for diepoxy[15]annulenone **1**. Previously, we reported that, on visible light irradiation, 4:7,10:13-diepoxy[15]annulenone **1**, a higher homologue of tropone (n = 1), an n = 3 member of [4n + 3]annulenones, undergoes a degenerate rearrangement,[2] whereby labeled ^{17}O from the carbonyl oxygen is transferred to one of the ether oxygens of the furan rings (the process establishes the photoequilibrium system I, Scheme 1). As the transformation is unique, mechanistic studies and the development of synthetic applications of the rearrangement are of special interest.

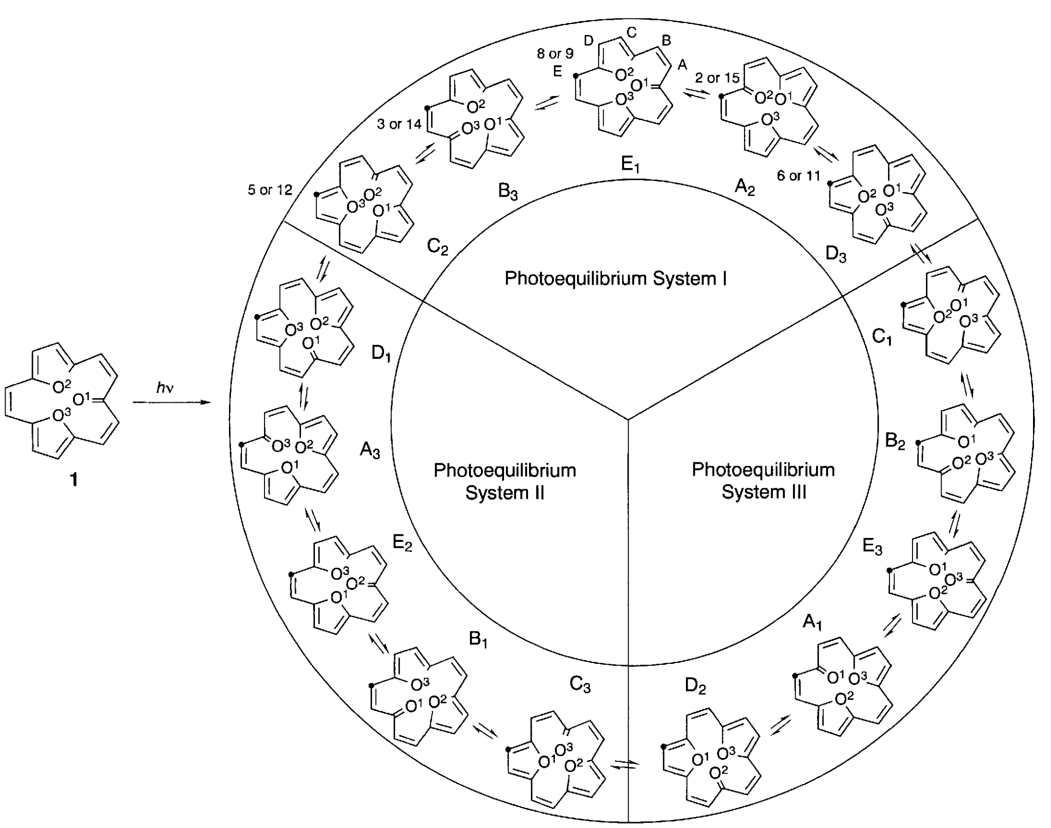
^{13}C and ^{17}O double enrichment studies have not only confirmed the degenerate rearrangement of **1**, but also given mechanistic insights into the reaction. Scheme 1 shows how the carbonyl-O/divinyl ether-O transportation rearrangements take place sequentially.

There are three photoequilibrium systems in the rearrangements. Photorearrangement starts from E_1 in equilibrium I, which has five ^{13}C positional isomers C_2, B_3, E_1, A_2 and D_3, while systems II and III contain positional isomers, D_1, A_2, E_2, B_1 and C_2, and C_1, B_2, E_3, A_1 and D_2, respectively. Isomers C_2 and D_3 in system I provide the link with systems II and III through adjacent positional isomers D_1 and C_1, respectively. It should be noted that the three oxygen atoms of a specific positional isomer (*e.g.* A) can freely exchange positions to give A_1, A_2 or A_3 to give 15 variations in all.

In order to follow the expected ^{13}C-movement in the ring, we prepared 5-dimethoxymethyl-2-furfural, with a ^{13}C-labelled formyl carbon, from which we could obtain C-8 position ^{13}C-labelled **1** *via* our previously reported synthetic route.[3] A further ^{17}O-label was added to this compound by warming it with $H_2{}^{17}O$ (10% in ^{17}O) in dioxane in the presence of a trace of conc. H_2SO_4.[4] The ^{13}C and ^{17}O doubly enriched **1** thus obtained was dissolved into CD_2Cl_2 with a trace of 1,4-diazabicyclo[2.2.2]octane (dabco) as singlet oxygen quencher. The mixture was subjected to photolysis [light source: 1 kW projector lamp, 0 °C, under N_2]. The time course of the rearrangement was monitored using ^{13}C and ^{17}O NMR spectroscopy.

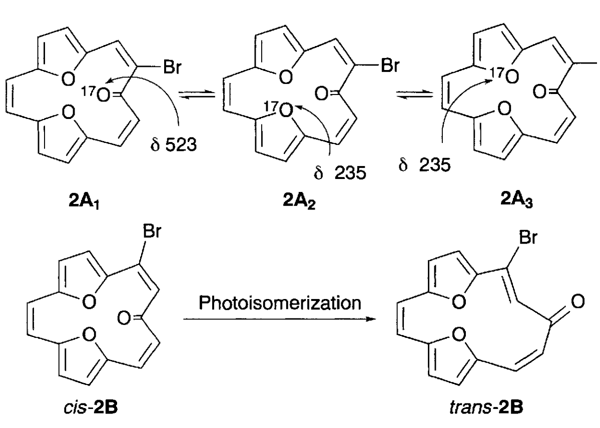
Before irradiation, the ^{13}C NMR spectrum exhibits a prominent signal at δ 110.6, which was assigned to C-8 and C-9, while other non-enriched carbon signals of **1** were almost negligible.

On continuing photoirradiation, the C-8 and C-9 signal decreased in intensity for the variable locations of the ^{13}C (●) introduced, see the numberings shown in Scheme 1. Firstly, a

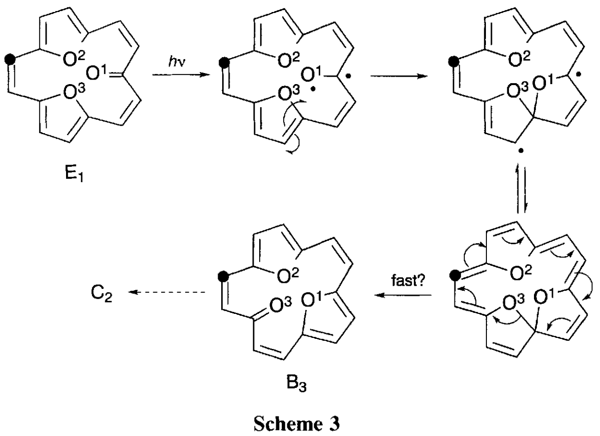


Scheme 1 A–E denotes positions of the ^{13}C atom(s) (●) in the annulenone ring, subscript 1–3 show the positions of delocalizable oxygen label attached to the carbonyl groups

new pair of signals appeared at δ 119.2 and 124.0. These were assigned to C-3,14 and C-2,15, respectively. At an earlier stage of the photoirradiation, this pair of signals progressively increased in intensity with irradiation, accompanying decreasing of the C-8,9 signals at the same rate. After further irradiation, the mixture spectrum showed a second set of increasing signals which appeared at δ 116.9 and 117.1 These are assigned to C-5,12 and C-6,11, respectively, again the initial C-8,9 signal progressively decreased relative to these new signals. After irradiation for 1 day, the five resonance lines (C-2,15, C-3,14, C-5,12, C-6,11, and C-8,9) were almost the same height. No intensity changes were observed thereafter. The observations indicate that the initial ^{13}C-label in E_1 is distributed evenly in the annulenone ring. The ^{17}O NMR spectrum taken at this stage exhibited a two ^{17}O signals at δ 525.8 ($C{=}^{17}O$) and 236.6 ppm (ether ^{17}O) with an intensity ratio of *ca.* 1 : 2. Therefore, we can conclude that the recombinations start from E_1 to produce A_2 and B_3 with the same populations, and then the second recombinations followed to establish photoequilibrium I.



Scheme 2



Scheme 3

The next task was to probe the mutual interconnection of equilibrium systems I–III, which required us to make a 'monosubstituted label' of **1**. We selected monobromo-diepoxy[15]annulenone **2**, a readily available substrate, which was prepared by reacting **1** with *N*-bromosuccinimide. Once ^{17}O-labels were put at the carbonyl oxygen of **2**, ^{17}O NMR could differentiate specific recombinant *e.g.* A_1, from other equilibrium congeners A_2 and A_3. The most simple way to prove that the equilibria are linked is to study the ratios of $[(A_2 + A_3)/A_1]$ in **2**, which should increase with irradiation time. For this purpose, it became essential to separate the isomers, *e.g.* A from B, C, · · · at different stages of the photoirradiation.

Bromo[15]annulenone **2**, ^{17}O-enriched at the carbonyl site ($C{=}^{17}O^1$, $2A_1$ in Scheme 2), was prepared and photoirradiated in similar manner. As expected, five positional isomers (2A–2E) could be isolated by HPLC in moderate yields. Their structures were determined by ^1H NMR spectroscopy.

Isomer $2A_1$ was found to exhibit a broad $C{=}^{17}O$ signal at δ 523 in CD_2Cl_2, which is shifted *ca.* 288 ppm downfield from the broad ^{17}O signal of the ether furan ring oxygen (δ 235), whose chemical shift should originate from either $2A_2$ or $2A_3$. The ratio $[(A_2 + A_3)/A_1]$ could be obtained by determining the ratio of the ether ^{17}O signal area of $(A_2 + A_3)$ at δ 235 relative to the $C{=}^{17}O$ signal area of A_1 at δ 523. As expected, after irradiation for 100 h, the ratio exceeded 1.7 : 1. Thus, our proposal for the existence of a photo-cycle joining the equilibria I, II and III was confirmed. Product analysis using multichannel photodiode array spectrophotometry indicated that *cis*-to-*trans* photoisomerization took place. This was the only experimental drawback. This event retards the photorecombinations, since reactive C=O groups of *cis*-isomers were placed outside of the rings (Scheme 2).

Finally, we propose the mechanism shown in Scheme 3. MM II calculations and X-ray data on **1**[4] suggest that the distance between the carbonyl oxygen and the α-carbon atoms of the furan rings in **1** is 3.36–3.41 Å. We consider that not only the distances, but also mobile frames are important to facilitate the photorecombinations.

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References

1 A. T. Balaban, M. Banciu and V. Ciorba, Annulenes, Benzo-, Hetero-Homo-Derivatives, and their Valence Isomers, vol. 1, ch. 5, pp 131–226, CRC Baca Raton, Florida, 1987.
2 H. Ogawa, M. Maruoka, T. Imoto, Y. Kato, M. Tomita, Y. Nogami and T. Koga, *J. Chem. Soc., Chem. Commun.*, 1991, 1775.
3 H. Ogawa, M. Inoue, T. Imoto, I. Miyamoto, H. Kato and Y. Taniguchi, *Angew. Chem., Int. Ed. Engl.*, 1983, **22**, 253; *Angew. Chem. Suppl.*, 1983, 243.
4 H. Dahn and M-N Ung-Truong, *Helv. Chim. Acta*, 1987, **70**, 2120.
5 H. Ogawa, N. Inoue, T. Imoto, I. Miyamoto, H. Kato, Y. Taniguchi, Y. Nogami and T. Koga, *J. Chem. Soc., Chem. Commun.*, 1989, 118.