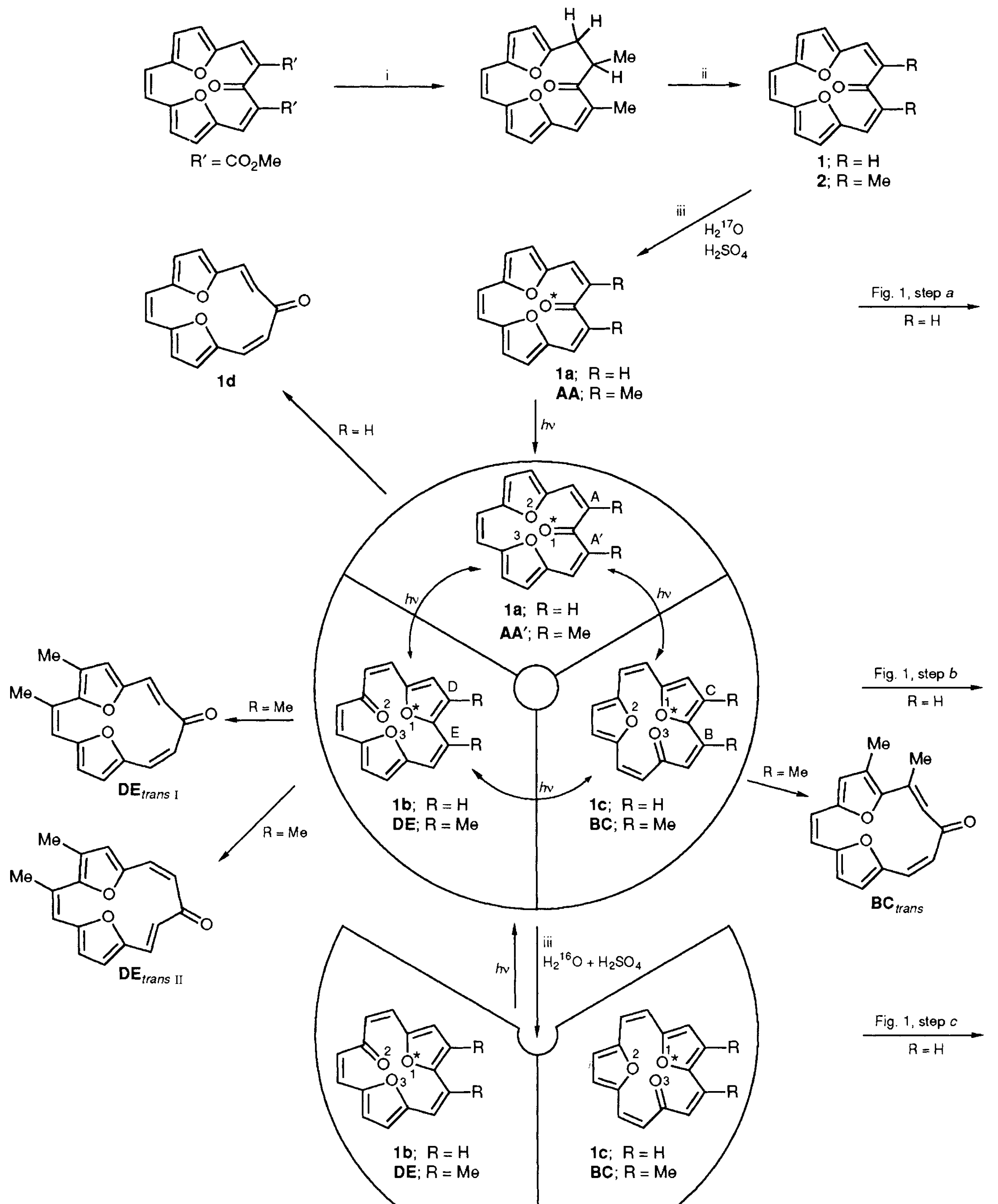
4 : 7,10 : 13-Diepoxy[15]annulenones exchange their Oxygen Bridges on Irradiation: ^{17}O NMR Spectroscopic and Chemical Verification of the Exchanges

Haru Ogawa,*[a] Misono Maruoka,[a] Taiji Imoto,[a] Yuko Kato,[b] Mitsuko Tomita,[b] Yasuyoshi Nogami[b] and Toshitaka Koga[b]

[a] *Faculty of Pharmaceutical Sciences, Kyushu University 62, Fukuoka 812, Japan*
[b] *Daiichi College of Pharmaceutical Sciences, Fukuoka 815, Japan*

A ^{17}O NMR study shows that, on visible light irradiation, the unsubstituted 4 : 7,10 : 13-diepoxy[15]annulenone **1** undergoes a degenerate rearrangement, by which the carbonyl oxygen of **1a** is interchangeable with the furan ring oxygens in **1b** and in **1c**; the 2,15-dimethyl analogue **2** undergoes similar oxygen-bridge exchange to give two positional isomers **BC** and **DE** in two different ways (i.e. *via* photo-irradiation and *via* a protonation–deprotonation sequence).

Diepoxyl[15]annulenone **1**[1,2] (Scheme 1), an $n = 3$ homologue of the $[4n + 3]$annulenones, is quite stable in contrast to the rather unstable tropone, the $n = 1$ member of the series. The stability of **1** is due to the presence of two inside oxygen bridges, that serve to keep the molecule in a regular pentadecagon-like geometry. We have now found that, on visible light irradiation, **1** undergoes a slow degenerate rearrangement, by which the carbonyl oxygen of **1a** (marked as $*\mathrm{O}_1$ in Scheme 1) is exchangeable equally with either of the furan ring oxygens, producing **1b** and **1c**.



Scheme 1 *Reagents and/or conditions*: i, $LiAlH_4$, $AlCl_3$, then NH_4Cl, ii, 2,3-dichloro-5,6-dicyanobenzoquinone (DDQ), CH_2Cl_2; iii, dioxane, 80 °C

[^{17}O]-Enriched diepoxy[15]annulenone **1a** was prepared by a warming **1** with $H_2{}^{17}O$ (10.2% ^{17}O) in dioxane (H_2SO_4 as catalyst),† giving the *trans*-diepoxy[^{17}O]annulenone **1d** as a by-product. Annulenones **1a** and **1d** (NMR spectra measured in CD_2Cl_2 at 67.70 MHz, 10^5 scans for the enriched samples) exhibited intense C=^{17}O signals at δ 538 and 486.9, respectively (step *a* in Fig. 1), while these compounds did not exhibit the oxygen signals of furan rings to a discernible extent (10^4 scans). This result indicates that [^{17}O]-enrichment took place exclusively at the carbonyl positions and that none of the furan ring oxygens in **1a** and **1d** are exchangeable with $H_2{}^{17}O$. Compound **1a** was dissolved in CH_2Cl_2 containing 0.1% 1,4-diazabicyclo[2.2.2]octane (DABCO), an efficient $^1O_2$ quencher, and subjected to photolysis for 5 days using a 400 W projector lamp at 27 °C. The C=^{17}O signal of **1a** decreased in intensity, and a new signal that is ascribable to the furan ring oxygens developed at δ 245.5 progressively with irradiation time (step *b*). This is direct confirmative evidence showing that the carbonyl oxygen of **1a** rearranges into the furan ring oxygen on irradiation. On heating the above sample with $H_2{}^{16}O$ in a similar manner, the ^{17}O content of the carbonyl oxygen decreased to give a spectrum in which the ^{17}O signal

---

† Preparation: non-enriched diepoxy[15]annulenone **1** (1.34 g), $H_2{}^{17}O$ (250 μl, 10.2% ^{17}O, 37.8% ^{18}O), dioxane (1.0 ml) and conc. H_2SO_4 (1 μl) were heated for 24 h at 80 °C. After neutralization of the reaction mixture with aq. $NaHCO_3$, the solvent was evaporated off and the residue chromatographed on a silica gel column.

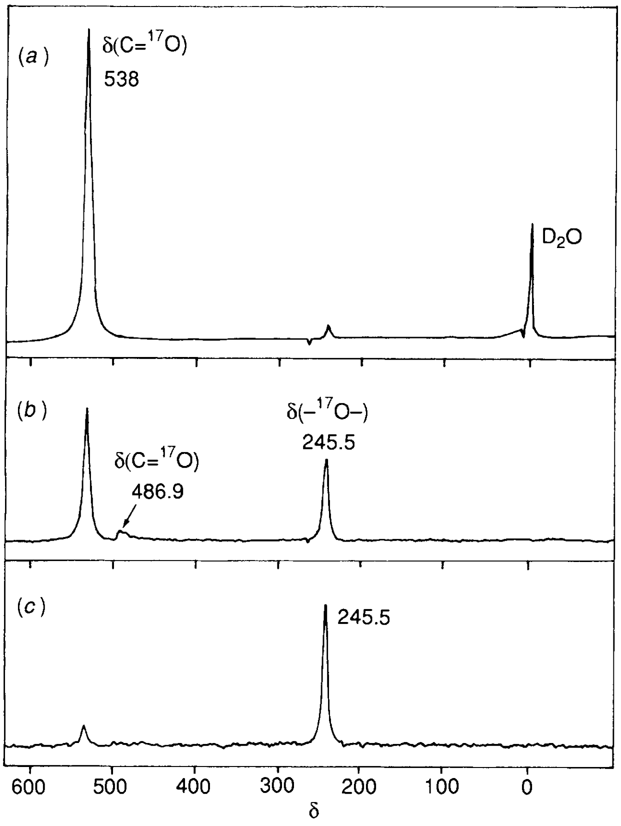


Fig. 1 ^{17}O NMR spectra at 67.70 MHz, in CD_2Cl_2 at 27 °C: (*a*) **1a**, ^{17}O-enriched sample; (*b*) after 3 days photoirradiation of **1a**; (*c*) removal of the ^{17}O from the sample of spectrum (*b*) by refluxing for 24 h at 90 °C in dioxane–H_2 ^{17}O

remained almost entirely at a position appropriate for the furan ring oxygens (step *c*). On further irradiation of this sample, the ^{17}O furan ring oxygen signal at δ 245.5 shifted again, in part, to δ 533.2 giving a spectrum showing two ^{17}O signals. From these ^{17}O NMR observations, we conclude that a degenerate photo-rearrangement takes place for **1a** by visible light irradiation. Compound **1a** reacts so slowly that even after 3 days the system was far from equilibrium. However, such prolonged irradiation did not lead to substantial photo-decomposition under conditions ensuring strict exclusion of oxygen.

Such an oxygen bridge exchange process could also be verified by the following chemical evidence. For this purpose, we chose 2,15-dimethyl-4 : 7,10 : 13 diepoxy[15]annulenone **2** as substrate. Compound **2** was prepared in 40% yield by the method in Scheme 1, and proved to be very suitable for studying the oxygen bridge exchanges. Only three positional isomers are possible in theory [for brevity, they are designated as **AA′** (the starting isomer), **BC** and **DE** as shown in Scheme 1]. If mono-substituted compounds had been selected as substrate, five positional isomers would have been produced.

The **AA′** isomer was irradiated for 5 days in CH_2Cl_2 at room temperature using a 400 W projector lamp. The mixture of photo-products was analysed by using a multichannel-photodiode array UV–VIS spectrophotometer (MCPD; Shimazu, model SPD-M6A). The result was completely in agreement with our expectation. The positional isomers **AA′**, **BC** and **DE** were separated on a silica gel column (CH_2Cl_2 as solvent), and their structures were determined by ^{1}H NMR and mass spectroscopy. It was found that the positional isomer ratio $\mathbf{BC}_{cis}/\mathbf{DE}_{cis}$ became *ca.* 1.2 after 57 h irradiation. Besides these positional isomers, the *trans*-isomers $\mathbf{BC}_{trans}$ and $\mathbf{DE}_{trans}$ I, II were detected in the spectrum. Thus, we have obtained confirmative chemical evidence that recombinant annulenones could be obtained from **2** by visible light irradiation.

The following results and deductions are relevant. (*i*) On dissolving the **AA′** isomer in a mixed acid consisting of CF_3CO_2H–CF_3SO_3H (1 : 1), the above oxygen bridge rearrangement took place in the dark instantaneously.‡ However, recombinant annulenones were not obtained in the absence of CF_3SO_3H. (*ii*) Under the acidic condition **2** undergoes rapid oxygen exchanges. This means that the two methyl groups in **2** force the molecule to adopt a W-form geometry at the five sequential sp^2 atom centres, even in the protonated form. The W geometry is the active conformation for causing the rearrangements. However, with other substitution patterns (for example, **BC** isomer) keeping a W-conformation becomes unfavoured on protonation because it holds one OH group on the inside of the ring, and, hence, the mono-*trans*-annulenyl ion possessing a sickle form (unreactive form for the oxygen bridge exchanges) becomes predominant. (*iii*) Epoxy group migrations often lead to useful rearrangements in synthetic chemistry (*e.g.* Payne reaction,[5,6] and transposition of ether linkages[7]). We consider that the present finding is of similar synthetic value, since versatile positional isomeric functional annulenones should be obtainable starting from single positional isomeric annulenones possessing OH, NHR and SH groups.

Received, 24th April 1991; Com. 1/01945G

References

1 H. Ogawa, M. Inoue, T. Imoto, I. Miyamoto, H. Kato, Y. Taniguchi, Y. Nogami and T. Koga, *J. Chem. Soc., Chem. Commun.*, 1989, 118 and references cited therein.
2 For the relationship between the photocycle of diepoxy[15]annulenone and that of bacteriorhodopsin, see H. Ogawa, H. Souji, T. Imoto, Y. Kato, Y. Nogami and T. Koga, *J. Chem. Soc., Chem. Commun.*, 1991, 498.
3 B. Payne, *J. Org. Chem.*, 1962, **27**, 3819.
4 T. R. Hoye and J. Suhadolnik, *J. Am. Chem. Soc.*, 1985, **107**, 5312.
5 M. W. Andersen, B. Hildebrandt and R. W. Hoffmann, *Angew. Chem., Int. Ed. Engl.*, 1991, **30**, 97.

---

‡ Equilibrium concentrations of the recombinant annulenones were variable under following acidic conditions (% determined by MCPD spectral data, using absorptions at 330 nm): $\mathbf{AA'}:\mathbf{BC}_{cis}:\mathbf{BC}_{trans}:\mathbf{DE}_{cis}:\mathbf{DE}_{trans}$ = 5.9 : 23.2 : 19.8 : 4.4 : 46.7 in CF_3CO_2H–CF_3SO_3H (1 : 1); and $\mathbf{AA'}:\mathbf{BC}_{cis}:\mathbf{BC}_{trans}:\mathbf{DE}_{cis}:\mathbf{DE}_{trans}$ = 0 : 27.7 : 26.1 : 20.9 : 25.3 in CF_3SO_3H.