

## Photoaddition of Maleimide to Anisole

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Irradiation in the maleimide–anisole charge-transfer band gives three isomeric 2 : 1 adducts which result formally from initial 1,2-, 2,3-, and 3,4-additions to the aromatic ring followed by Diels–Alder addition of a second maleimide molecule. The additions are strongly inhibited by the strong proton donor trifluoroacetic acid, yet are markedly promoted by methanol, though not by acetonitrile. In the case of methanol, unfiltered irradiation greatly promoted formation of the isomeric adduct derived formally by 1,2-cycloaddition to anisole, but this selective effect was not observed on irradiation exclusively in the charge-transfer band. Maleic anhydride does not undergo corresponding reactions under comparable conditions.

ALTHOUGH many photoaddition reactions of electron-acceptor alkenes to aromatic substrates have been reported, the precise nature of the processes involved has been the subject of continued investigation.<sup>1–5</sup> Thus the reactions of maleimides with benzene and substituted benzenes are believed to proceed by pathways different from those of the corresponding reactions of maleic anhydride, although the resulting 2 : 1 adducts are of similar structures in the two cases.<sup>1,6</sup> The former reactions are thought to occur by  $n \rightarrow \pi^*$  excitation of the maleimide and addition of the excited species to the aromatic compound to give the 'cyclobutane'-type 1 : 1 photoadduct (1) which can be trapped as shown (Scheme). With maleic anhydride the addition reactions involve charge-transfer excitation, and appear to proceed *via* a zwitterionic intermediate (2) which can be intercepted by proton donors to give an arylsuccinic anhydride,<sup>3</sup> but adducts of type (3) have been intercepted by tetracyanoethylene,<sup>4</sup> or more effectively by *N*-phenylmaleimide.<sup>5</sup> The addition of maleimides to benzene does not appear to involve either charge-transfer excitation or the formation of a zwitterionic intermediate analogous to (2), and proton donors do not divert the addition process to give succinimides.<sup>6</sup> Solutions containing maleimide and benzene do exhibit what appears to be charge-transfer absorption, but it has not proved possible to locate the position of  $\lambda_{\text{max}}$  with any precision since the strongest absorption occurs in the range 230–280 nm where it is overlaid by the absorptions of benzene and maleimide themselves.<sup>6</sup>

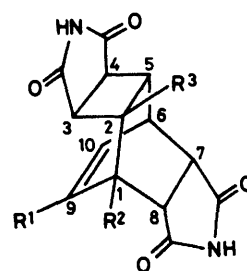
The purpose of the present work was to discover whether the charge-transfer mechanism found with maleic anhydride as addend, but not with maleimide, could be induced to occur with maleimide by choice of a relatively more nucleophilic substituted benzene. It was hoped that the expected bathochromic shift of the charge-transfer absorption band to a region beyond those in which the maleimide and aromatic compound themselves absorb would permit selective excitation of the charge-transfer transition. A further purpose was to

ascertain whether this change of mechanism would render photoaddition of the maleimide sensitive to the presence of proton donors, as with maleic anhydride. Anisole was selected as a potentially suitable aromatic component since it shows charge-transfer absorption with maleimide ( $\lambda_{\text{max}}$  ca. 260 nm) which extends well beyond 320 nm where anisole and maleimide do not themselves absorb to any significant extent.

### RESULTS AND DISCUSSION

A filter solution was used to exclude radiation of wavelength <327 nm, and thereby ensure selective charge-transfer excitation. Irradiation of a 1% solution of maleimide in anisole in the absence of the filter led to the three 2 : 1 photoadducts [(4)–(6)]. For the first time in this type of work, the mixture of photoadducts [(4)–(6)] has been successfully resolved and the individual adducts have been isolated, albeit in low yield. The structures have been assigned from <sup>1</sup>H n.m.r. spectra and by analogy with the spectra of corresponding adducts between maleimides and several alkylbenzenes.<sup>7</sup>

Previous studies with maleimide or maleic anhydride and substituted benzenes<sup>2,7,8</sup> led us to expect an initial predominant 3,4-addition to give 9-methoxytricyclo-[4.2.2.0<sup>2,5</sup>]dec-9-ene-3,4-*exo*:7,8-*endo*-bisdicarboximide (4), but although this was obtained, it was the adduct



- (4) R<sup>3</sup> = R<sup>2</sup> = H, R<sup>1</sup> = MeO  
 (5) R<sup>3</sup> = MeO, R<sup>1</sup> = R<sup>2</sup> = H  
 (6) R<sup>3</sup> = R<sup>1</sup> = H, R<sup>2</sup> = MeO  
 (7) R<sup>3</sup> = R<sup>1</sup> = R<sup>2</sup> = H  
 (8) R<sup>3</sup> = R<sup>2</sup> = H, R<sup>1</sup> = Me  
 (9) R<sup>3</sup> = R<sup>1</sup> = H, R<sup>2</sup> = Me  
 (10) R<sup>3</sup> = Me, R<sup>1</sup> = R<sup>2</sup> = H

formed in the least amount. It was the least soluble of the three adducts, and tended to precipitate from the irradiated solution together with ill-defined polymeric material (cyclobutane dimers of maleimide were sought but not found). The <sup>1</sup>H n.m.r. spectrum (trifluoro-

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<sup>1</sup> D. Bryce-Smith, *Pure Appl. Chem.*, 1973, **34**, 193.

<sup>2</sup> D. Bryce-Smith and A. Gilbert, *Chem. Comm.*, 1968, 19.

<sup>3</sup> D. Bryce-Smith, R. Deshpande, A. Gilbert, and J. Grzonka, *Chem. Comm.*, 1970, 561.

<sup>4</sup> W. Hartmann, H. G. Heine, and L. Schrader, *Tetrahedron Letters*, 1974, 883 and 3101.

<sup>5</sup> D. Bryce-Smith, R. Deshpande, and A. Gilbert, *Tetrahedron Letters*, 1975, 1627.

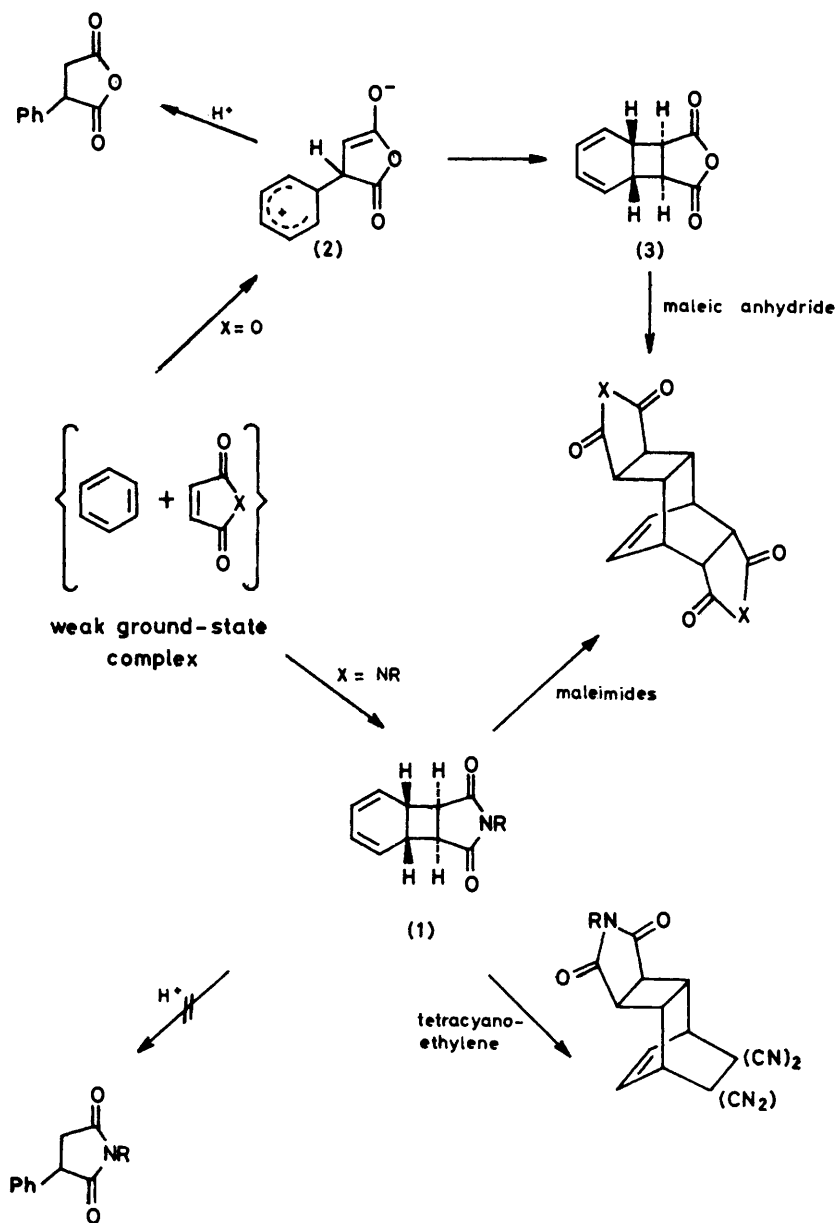
<sup>6</sup> D. Bryce-Smith and A. Gilbert, *Tetrahedron*, 1977, 2459.

<sup>7</sup> (a) J. S. Bradshaw, *Tetrahedron Letters*, 1966, 2039; (b) C. E. Rees, Ph.D. Thesis, Reading University, 1973.

<sup>8</sup> D. Bryce-Smith and A. Gilbert, *J. Chem. Soc.*, 1965, 918.

acetic acid) shows a multiplet ( $\delta$  6.60) for one vinylic proton and a one-proton complex multiplet ( $\delta$  4.70). This latter signal is assigned to the bridgehead proton at C-1, adjacent to the methoxy group and deshielded by it. The methoxy-signal at ( $\delta$  4.10) is deshielded by 28 Hz (at 60 MHz) compared with the methoxy-signals of (5)

third adduct was 1-methoxytricyclo[4.2.2.0<sup>2,5</sup>]dec-9-ene-3,4-*exo*:7,8-*endo*-bisdicarboximide (6). The <sup>1</sup>H n.m.r. spectrum showed two chemically distinct vinyl resonances [ $\delta$  6.92 (d,  $J_{9,10}$  1.5 Hz) and  $\delta$  6.58 (doublet of doublets,  $J_{10,9}$  1.5,  $J_{10,6}$  4 Hz)] with the lower-field signal showing vinyl-vinyl, but not vinyl-bridgehead,



SCHEME

and (6) (each at  $\delta$  3.63, see below), and is fully consistent with the vinyl ether assignment. One of the two major 2:1 adducts was identified as 2-methoxytricyclo[4.2.2.0<sup>2,5</sup>]dec-9-ene-3,4-*exo*:7,8-*endo*-bisdicarboximide (5), on the basis of a two-proton resonance at  $\delta$  6.57. This structure implies an initial 1,2-addition to anisole, only observed previously in photoadditions of alkenes to benzonitrile<sup>9a</sup> and of acrylonitrile to anisole.<sup>9b</sup> The

coupling. The formation of this adduct implies an initial 2,3-addition to anisole. The ratios (4):(5):(6) were reproducibly *ca.* 1:10:10; these adducts were shown to be photostable under the reaction conditions.

The stereochemistries of the 3,4- and 7,8-ring junctions

<sup>9</sup> (a) J. G. Atkinson, D. E. Ayer, G. Büchi, and E. W. Robb, *J. Amer. Chem. Soc.*, 1963, **85**, 2257; (b) M. Ohashi, Y. Tanaka, and S. Yamada, *J.C.S. Chem. Comm.*, 1976, 800.

cannot be assigned unambiguously from the spectroscopic data alone. However, the proposed *exo*-3,4- and *endo*-7,8-configurations are consistent with the known stereochemistry of the 2:1 photoadducts of maleic anhydride and maleimide with benzene,<sup>10</sup> and are supported to some extent by the observation of resonances between  $\delta$  2.7 and 3.0 for each adduct which are tentatively assigned to the *endo*-protons at C-3 and C-4.

Irradiation through a filter which excluded excitation other than in the charge-transfer band gave the three 2:1 adducts [(4)—(6)] in essentially the same total yields and ratios as without the filter. Thus exclusive charge-transfer excitation gives the same result as excitation over a broader wavelength range involving additional direct individual excitation of anisole and maleimide. One might suspect that in the latter case, intermolecular redistribution of energy rapidly occurs to give the same low-energy charge-transfer state as is exclusively formed using filtered radiation (but contrast the results for 10M-methanol described below). In any event, it is evident that maleimide can be induced to add to the benzene ring by charge-transfer excitation rather than by direct  $n \rightarrow \pi^*$  excitation ( $\lambda_{\max}$  270 nm;  $\epsilon$  800 l mol<sup>-1</sup> cm<sup>-1</sup> in cyclohexane). Accordingly, the effect of proton donors was investigated in the hope of intercepting a zwitterionic intermediate analogous to (2) as a mixture of *p*-methoxyphenylsuccinimides.

In the presence of 1M-trifluoroacetic acid, formation of the 2:1 adducts (4)—(6) was totally suppressed using filtered radiation as before, and almost totally suppressed in the absence of the filter, but no methoxyphenylsuccinimides were detected. This suppression of adduct formation contrasts with the relatively minor adverse effect of trifluoroacetic acid on the photoaddition of maleimide to benzene. Although no phenylsuccinimide was detected in that case, by analogy with the effect of the acid on photoaddition of maleic anhydride to benzene<sup>3</sup> some acid-promoted formation of methoxyphenylsuccinimides from maleimide and anisole was expected.

The use of methanol gave even more surprising results, for this weaker proton donor readily diverts the maleic anhydride-benzene photoreaction to the formation of phenylsuccinic anhydride, yet it is virtually without effect on the photoaddition of maleimide to benzene (see later). Irradiation (unfiltered) of maleimide and anisole in the presence of 1M-methanol gave a total yield of 2:1 adducts similar to that in the absence of methanol, but the ratios (4):(5):(6) were changed reproducibly from 1:10:10 to 1:30:10, *i.e.* initial 1,2-addition was relatively favoured. With 10M-methanol, the total yield of adducts was increased *ca.* threefold, and the product ratios were *ca.* 1:60:10 respectively; again no methoxyphenylsuccinimides were detected. The effect of the increased proportion of methanol was therefore largely

to promote formation of (5) which arises *via* an initial 1,2-addition to anisole.

These irradiations of anisole and maleimide in the presence of methanol were repeated using a filter to permit only charge-transfer excitation. 1M-Methanol had no significant effect on either the chemical yields or isomer ratios, but although 10M-methanol led to doubling of the total chemical yield of the 2:1 adducts, there was only a slight change in the above isomer ratios (to 1:10:15). Thus the enhancement of initial 1,2-addition in 10M-methanol appears to be associated with excitation at wavelengths <327 nm, a surprising result, especially in view of the observation that 10M-methanol markedly increased the total yield of 2:1 adducts using both filtered and unfiltered radiation. We were at first inclined to suspect an experimental artefact, but the results were confirmed on repetition of the experiments. The enhancement of the yield of 2:1 adducts in the presence of a large excess of methanol is associated with less formation of insoluble polymeric material. No methoxyphenylsuccinimides were detected as with trifluoroacetic acid as proton donor.

The previously reported photoaddition of maleimide to benzene in the absence of proton donors was repeated using unfiltered radiation. The yield of adduct (7) agreed well with that previously found.<sup>11</sup> In the presence of 10M-methanol, the yield of 2:1 adduct was decreased by *ca.* 10%, but less polymeric material was produced.

Thus methanol slightly inhibits the photoaddition of maleimide to benzene, but markedly promotes the corresponding 1,2-addition to anisole, giving the isolated adduct (5). The effect does not appear to be one of solvent polarity alone since the use of 10M-acetonitrile in place of methanol gave only traces of 2:1 adducts and led mainly to ill-defined polymeric material.

The failure of proton donors to induce the formation of methoxyphenylsuccinimides from anisole and maleimide under conditions of charge-transfer excitation is slightly surprising in view of the effects of proton donors on the charge-transfer photoaddition of maleic anhydride to benzene, but less so in the light of the further observation that maleic anhydride and anisole do not form either methoxyphenylsuccinic anhydrides or 2:1 adducts on irradiation in the charge-transfer band ( $\lambda_{\max}$  *ca.* 285 nm) either in the presence or in the absence of methanol or trifluoroacetic acid. The attempted use of benzophenone as a photosensitizer (proton donors absent) gave a trace of material with *m/e* 304 corresponding to a 2:1 adduct, but this could not be resolved into pure isomers.

It is interesting to compare the photoaddition of maleimide to anisole with that to toluene. Unfiltered irradiation of maleimide in toluene under the conditions used for the corresponding experiment with anisole gave a 2:1 mixture of the 2:1 adducts (8) and (9) which arise formally by initial 3,4- and 2,3-additions to toluene: there was no conclusive evidence for the formation of (10), which might arise *via* an initial 1,2-addition to toluene analogous to that which occurs with anisole. It

<sup>10</sup> D. Bryce-Smith and M. A. Hems, *Tetrahedron Letters*, 1966, 1895; D. Bryce-Smith, G. I. Fray, and B. Vickery, *J. Chem. Soc. (C)*, 1967, 390.

<sup>11</sup> M. A. Hems, Ph.D. Thesis, Reading University, 1967.

seems reasonable to conclude from this that the 1,2-addition favoured with anisole arises from the presence of the oxygen atom, with its ability to act as an *n*-donor to the maleimide. Such electron donation might involve methanol-promoted complexation which locates the maleimide molecule in proximity to the 1,2-bond, thus favouring its addition at this position. But the reluctance of maleic anhydride to react similarly with anisole remains unexplained

#### EXPERIMENTAL

N.m.r. spectra ( $\text{CF}_3\text{CO}_2\text{H}$  solution) were recorded on a Varian T60 spectrometer, i.r. spectra (Nujol mulls) on a Perkin-Elmer 157G instrument, and mass spectra at 20 and/or 70 eV using an A.E.I. MS12 spectrometer: accurate masses were determined using a A.E.I. MS 902 instrument at the National Institute for Research in Dairying (Shinfield, Berkshire). U.v.-visible spectra were obtained using a Unicam SP 1800 or Perkin-Elmer 402 spectrometer. Because of the intense absorption of anisole at wavelengths  $< 285$  nm it proved impractical to determine accurately the  $\lambda_{\text{max}}$  of its complexes with maleimide and maleic anhydride; the approximate values given in the text are deduced by extrapolation.

The lamp source in all irradiations was a Hanovia 100 W medium-pressure mercury arc. The filter solution was 1M-potassium nitrate, and at a path length of 1 cm, this effectively absorbs all wavelengths  $< 327$  nm.

*Irradiation of Maleimide in Anisole.*—Direct irradiation. A solution of maleimide (1.20 g) in anisole (120 ml) was irradiated in a quartz water-cooled cell for 12 h with continuous stirring. The resultant pale yellow solution was filtered from the insoluble cream deposit and concentrated *in vacuo* to a pale orange oil which slowly solidified.

The insoluble cream deposits from three such reactions ( $3 \times 120$  mg) were combined and extracted with diethyl ether (Soxhlet). The ether-soluble material was recovered by concentration *in vacuo* and triturated with acetone (*ca.* 1 ml) to give 9-methoxytricyclo[4.2.2.0<sup>2,5</sup>]dec-9-ene-3,4-exo:7,8-endo-bisdicarboximide (4) (10 mg, from 3 runs) as a white powder, m.p.  $360^\circ\text{C}$  (Found:  $M^+$ , 302.09111.  $\text{C}_{15}\text{H}_{14}\text{N}_2\text{O}_5$  requires  $M$ , 302.09026);  $\delta(\text{CF}_3\text{CO}_2\text{H})$  9.90 (NH, br s), 9.70 (NH, br s), 6.60 (H-10, m), 4.70 (1 H, m), 4.3–3.9 (1 H, m), 4.10 (3 H, s,  $\text{OCH}_3$ ), 3.8–3.2 (4 H, complex m), 2.95 (1 H, br s), and 2.75 (1 H, s);  $\nu_{\text{max}}$  3 150, 3 050, 1 770, 1 700, 1 345, 1 215, 1 197, 1 175, 990, 855, and  $845\text{ cm}^{-1}$ .

The orange oily solid was triturated with a large volume of diethyl ether (*ca.* 70 ml) and the insoluble cream material (340 mg) was filtered off and extracted with acetone to yield 2-methoxytricyclo[4.2.2.0<sup>2,5</sup>]dec-9-ene-3,4-exo:7,8-endo-bisdicarboximide (5) as an insoluble powder (150 mg) which was recrystallised from acetone; m.p.  $250$ – $254^\circ\text{C}$  (decomp.) (Found: C, 59.45; H, 4.85; N, 8.5%;  $M^+$ , 302.08905.  $\text{C}_{15}\text{H}_{14}\text{N}_2\text{O}_5$  requires C, 59.6; H, 4.65; N, 9.25%;  $M$ , 302.09026);  $\delta(\text{CF}_3\text{CO}_2\text{H})$  9.95 (NH, br s), 9.70 (NH, br s), 6.57 (H-9 and H-10, m), 4.00 (1 H, complex m), 3.63 (3 H, s,  $\text{OCH}_3$ ), 3.80–3.35 (4 H, complex m), and 2.77 (2 H, d);  $\nu_{\text{max}}$  3 200, 1 775, 1 725, 1 715, 1 350, 1 295, 1 255, 1 195, 1 189, 1 125, 1 070, 1 015, 855, 840, 785, and  $775\text{ cm}^{-1}$ . The ether filtrate was concentrated *in vacuo* and the residue triturated with diethyl ether (25 ml). The in-

soluble material was filtered off to give 1-methoxytricyclo[4.2.2.0<sup>2,5</sup>]dec-9-ene-3,4-exo:7,8-endo-bisdicarboximide (6) (52 mg) which on recrystallisation from acetone-light petroleum had m.p.  $270$ – $275^\circ\text{C}$  (decomp.) (Found:  $M^+$ , 302.08993.  $\text{C}_{15}\text{H}_{14}\text{N}_2\text{O}_5$  requires  $M$ , 302.09026);  $\delta$  ( $\text{CF}_3\text{CO}_2\text{H}$ ) 9.97 (NH, br s), 9.75 (NH, br s), 6.92 (H-9, apparent d), 6.58 (H-10, m), 4.0 (1 H, m), 3.8–3.0 (4 H, complex m), 3.63 (3 H, s,  $\text{OCH}_3$ ), and 2.77 (2 H, br d);  $\nu_{\text{max}}$  3 150, 3 050, 1 760, 1 705, 1 355, 1 255, 1 190, 1 160,  $845$ , and  $685\text{ cm}^{-1}$ .

The ratio (4) : (5) : (6) was assessed by n.m.r. spectroscopy of the unseparated mixtures.

*Filtered irradiation.* These experiments were performed using 1% solutions (28 ml) of maleimide in anisole. On 12 h irradiation, such solutions gave *ca.* 40 mg of (4)–(6), ratios 1 : 10 : 10.

The above reactions of 1% maleimide in anisole were repeated in the presence of 1M-trifluoroacetic acid and 1M- and 10M-methanol, both with and without the potassium nitrate filter solution. The work-up procedures were similar to those outlined above. In the presence of the acid, only very small amounts of 2 : 1 adducts could be detected by mass spectroscopy after the unfiltered irradiation, and no evidence was obtained for the formation of any such products in the presence of the filter. In the absence of the filter solution, and in the presence of 1M- and 10M-methanol, the total yields of the products were *ca.* 200 and 600 mg, respectively: the isomer ratios as deduced by n.m.r. spectroscopy are given in the text. Repetition of the filtered irradiation in the presence of 1M- and 10M-methanol gave 40 and 90 mg, respectively, of the combined 2 : 1 adducts.

*Irradiation of Maleic Anhydride in Anisole.*—1% Solutions (150 ml) of maleic anhydride in anisole were irradiated in the absence and presence of 1M-methanol or 1M-trifluoroacetic acid for 12 h. Removal of the volatile materials (rotary evaporator; water pump pressure) gave a brown viscous oil which was only partly soluble in ether. Neither fraction consisted (n.m.r. or mass spectroscopy) of 2 : 1 or 1 : 1 adducts (including *p*-methoxyphenylsuccinic anhydrides). The incorporation of benzophenone (1.86 g) into the irradiation mixture in the absence of a proton donor gave traces of a white ether-insoluble solid; this showed anhydride absorption (i.r.) and n.m.r. signals at  $\delta$  6.4 and 4.0–2.8, and had significant *m/e* values at 304 (2 : 1 adduct), 206 (1 : 1 adduct), and 108 (anisole). The amount was insufficient to permit isolation and identification of these adducts.

*Irradiation of Maleimide in Toluene.*—A 1% solution of maleimide in toluene (120 ml) was irradiated for 12 h. The precipitated solid (690 mg) was filtered off. The i.r. and n.m.r. spectra were identical with those reported.<sup>7b</sup> In particular, n.m.r. signals at  $\delta$  2.01 and 1.63 (ratio 2 : 1) are assigned to the methyl groups in (8) and (9), respectively. A low-intensity resonance at  $\delta$  1.40 (*ca.* 2% of the total methyl resonances) could result from the methyl group in (10) but this could not be confirmed by separation of the isomers.

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