Ketone-initiated, hydrogen-abstraction reactions of 2-methoxytetrahydropyran*

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The study of photochemical reactions of carbohydrates is complicated by several factors. Most of the compounds have little or no absorbance in the accessible ultraviolet. This leads to the possibility of sensitized reactions originating from chromophoric impurities. The polyfunctionality of carbohydrates gives rise to a large number of sites of comparable reactivity, leading to complex product mixtures. In addition, many of the photoproducts absorb light more strongly than the starting materials, so that secondary reactions may obscure primary processes¹.

Efforts to understand the basic photochemical processes are frustrated further by the wide variety of conditions employed in the literature reports². Researchers interested in textiles are concerned with the effect of dyes on the photochemistry of cellulose³. Others have studied the effects of inorganic additives on carbohydrate photochemistry⁴. In most instances, oxygen is present in the system, which promotes more rapid reaction, but also leads to extensive degradation, in some cases all the way to carbon dioxide¹.

In many instances, authors report working with materials that show a weak absorption maximum at 260–280 nm⁵, which has been ascribed to both the openchain, carbonyl form of the compounds⁶ and also to an absorption band of the "acetal chromophore" itself⁷. Our experience has been that most commercial samples of carbohydrates absorb in this region, but careful recrystallization usually removes the absorbing impurities completely. It might be inferred from this that impure samples have been used occasionally in the past; this conclusion was also reached by Bos⁸.

The most plausible impurities would be carbonyl compounds, the absorption being due to the $n \rightarrow \pi^*$ transition. Such groups are almost certainly present as irregularities in cellulose⁸. It was with these considerations in mind that we decided to examine the photochemistry of 2-methoxytetrahydropyran (1), a model for a glycoside, in the presence of ketones.

^{*}Part I of a series "Photochemistry of Carbohydrate Model Compounds".

A previous report⁹ of the reaction of 1, benzophenone, and benzene in the presence of u.v. light gave the major products as tetrahydropyran-2-one (2) and methyl pentanoate (3) (Eq. 1), formed in a ratio of 16:1 and a total yield, based on starting material consumed, of 41%. This product-ratio seemed surprising as one might expect that the loss of a methyl radical (path A, Eq. 2) from the proposed intermediate 2-methoxytetrahydropyran-2-yl radical would be less favorable than the loss of the primary alkyl radical (path B) on the basis of relative radical stabilities, whereas the reported product-ratio indicated the opposite. Furthermore, di-*tert*-butyl peroxide was reported to give 3 as the major, volatile product in a thermal reaction, and no 2 was found¹⁰.



In this paper, we report: (a) the finding of another, major photoproduct in the foregoing benzophenone-benzene system, indicating that path B is the major pathway; (b) a solvent effect favoring path A in changing to *tert*-butyl alcohol; and (c) a change in product-distribution in changing the initiator from benzophenone to acetone.

RESULTS

Irradiation of 1 in the presence of acetone or benzophenone and in the absence of oxygen led to the production of 2 and 3. In addition, with benzophenone in benzene, methyl 5-phenylpentanoate (4) was a major product. This product was not identified in the previous report⁹. The results (Table I) indicate that the product distribution is a function of both the solvent and the ketone.

The products were identified by comparison of v.p.c. retention-times on at least two different columns and i.r. or n.m.r. spectral comparison of samples collected from the v.p.c. column with those of authentic materials. Quantitative results were obtained by v.p.c. and assumed a molar flame-ionization response proportional to molecular weight.

Irradiation ^b	Sensitizer	Solvent	1	3	2	4	<i>Minor^c</i>
1	Acetone	tert-BuOH	53	18	5	_	14
2	Acetone	benzene	100	0	0	0	0
3	Benzophenone	tert-BuOH	64	3	7		0
4	Benzophenone	benzene	58	7	14	22	104

TABLE I COMPOSITION OF SOLUTIONS AFTER IRRADIATION⁴

^eV.p.c. analysis of products at least as volatile as benzophenone (mole percent of original concentration ·). ^bSee Table II for details. ^cMinor products not identified; yield based on original concentration 1. ^dIncludes 3% biphenyl.

In addition to these major products, several other, minor products appeared in the chromatograms but, with the exception of biphenyl in Irradiation 4, were not identified. Biphenyl was identified only by its retention time on two columns. Also, some relatively nonvolatile products must have been formed in some cases, as not all of the starting material could be accounted for by the observed products. These minor products varied, both in amount and retention time, with the reaction conditions.

The difference in major-product ratio might *a priori* be attributed to a lack of stability of 3 and/or 2 in the benzophenone and acetone systems, respectively. However, in control experiments these products were found to decompose to the extent of only 15% or less, even when irradiated for the full time of the irradiations of 1. As these products were gradually formed during the irradiation of 1, the average exposure to the reaction conditions would have been less than in the control experiments. Therefore, product instability cannot account for the difference.

DISCUSSION

The mechanism previously proposed^{9,11}, and shown (in part) in Eq. 2, accounts for 2 and 3. In addition, compound 4 observed in Irradiation 4 can be accommodated by a mechanism involving reaction of the methyl 5-pentanyloate radical with the benzene solvent, as shown in Eq. 3.



Thus, 3 and 4 are both derived from the ring-opening path B shown in Eq. 2. Path B, therefore, accounts for 78% of the identified products in Irradiation 1 and 67% in Irradiation 4. In Irradiation 3, however, path B accounts for only 30% of the observed products.

No explanation of the lack of reaction in the acetone-benzene system (Irradiation 2) is evident. The ketone absorbs essentially all of the u.v. light transmitted by the pyrex vessel in both Irradiations 2 and 4. Also, benzene is known to be ineffective in quenching the triplet state of acetone in the gas phase¹².

Comparison of Irradiations 1 and 3 indicates that the ketone may have an effect on the product distribution. Comparison of Irradiations 3 and 4 indicates that the solvent may also influence the reaction.

There are several possible rationales for these effects. The formation of relatively nonvolatile products via radical-coupling reactions could account for the differences. Although dimethyl decanedioate was not formed in proportions greater than 1% in these irradiations, as shown by v.p.c., coupling of the open-chain radical with the ketyl radical formed from benzophenone in Irradiation 3 is a possibility.

A second rationale is that Path B is potentially reversible, whereas Path A is not. The lifetimes of the various intermediates may well vary in the different media, and the importance of this reversibility could thus change.

Finally, conformational effects could be important. Although the conformational composition of 1 did not alter appreciably in changing from benzene to *tert*-butyl alcohol (see Experimental section), the conformations involved in the product-forming steps could be stabilized to differing degrees in the various media.

EXPERIMENTAL

Starting materials. — Reagent-grade benzene was stirred with sulfuric acid and distilled. *tert*-Butyl alcohol was refluxed with and distilled from calcium hydride. Acetone was distilled from potassium permanganate. Benzophenone was recrystallized twice from 95% ethanol. 2-Methoxytetrahydropyran (1) was prepared by the method of Woods and Kramer¹³. No impurities were detected by n.m.r. or v.p.c.

Irradiations. — Irradiations were carried out in a Rayonet Photochemical Reactor (Southern New England Ultraviolet) equipped with RPR 3000 lamps and pyrex tubes as filters. This procedure assured that only the ketones absorbed light. Dilute solutions (see Table II) were deoxygenated by bubbling nitrogen through the solution for 20-30 min prior to and during irradiation, or by at least three freeze-pump-thaw cycles followed by sealing the tube *in vacuo*.

TABLE II

IRRADIATIONS

Irradiation	Solvent (ml)	Ketone (g)	1 (g)	Time (h)	
1	<i>tert-</i> BuOH (18)	acetone (1.6)	0.628	21	
2	Benzene (18)	acetone (2.4)	0.585	36	
3	tert-BuOH (20)	benzophenone (0.185)	0.122	16	
4	Benzene (20)	benzophenone (0.188)	0.118	19	

Control experiments. — Two solutions were prepared, degassed by three freezepump-thaw cycles, sealed *in vacuo*, and irradiated as described for 21 h. The first solution, composed of 0.180 g of 2, 1.6 g of acetone, and 18 ml of *tert*-butyl alcohol, showed 84% of the original concentration of 2 and no new peaks in the gas chromatogram after irradiation. The second solution consisted of 0.089 g of 3, 0.184 g of benzophenone, and 20 ml of benzene, and after irradiation it showed 88% of the original concentration of 3 and a new peak corresponding to 12% of the original concentration of 3.

Product analysis. — Products were identified by preparative v.p.c. followed by spectral comparison with known samples. Methyl pentanoate (3) was identified by n.m.r. spectroscopy, whereas tetrahydropyran-2-one (2) and methyl 5-phenyl-pentanoate (4) were identified by i.r. spectroscopy. All compounds showed retention times identical to authentic samples on two or more v.p.c. columns. Biphenyl was identified in Irradiation 4 by retention-time only.

Quantitative analysis was effected by v.p.c. A molar response proportional to molecular weight was assumed for the flame-ionization detector for the identified products. Unidentified, minor products were assumed to have a response equal to that of 1. Columns used were: 10% Carbowax 20M on 60–80 mesh Chromosorb W, $1/8 \text{ in.} \times 6 \text{ ft}$; 20% Carbowax 1500 on 100–120 mesh Gas Chrom Q, $1/8 \text{ in.} \times 20 \text{ ft}$; and 3% OV-17 on 100–120 mesh Gas Chrom Q, $1/8 \text{ in.} \times 4 \text{ ft}$. Preparative v.p.c. was performed on 5% SE-30 on 60–70 mesh Anakrom ABS, $1/4 \text{ in.} \times 5 \text{ ft}$.

N.m.r.-spectral analysis of the conformation of 2-methoxytetrahydropyran (1). — N.m.r. spectra of 1 were recorded in benzene and tert-butyl alcohol. The signal for H-2 ("anomeric proton") was then used to determine the axial:equatorial ratio according to the method of Pierson and Runquist¹⁴, who determined the ratio for neat 1. The distance between the outer peaks (shoulders) of the broad triplet was 5.5 ± 0.5 Hz in benzene and 6.5 ± 0.5 Hz in tert-butyl alcohol. These values correspond to $86 \pm 10\%$ and $69 \pm 10\%$ axial methoxyl, respectively. Pierson and Runquist found a value of 72% for the neat liquid.

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