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PHOTOCHEMICAL BEHAVIOUR OF 5-BROMO-2-FURYL KETONES

SYNTHESIS OF 5-ARYL-2-FURYL KETONES

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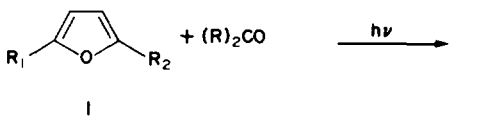
Abstract—The photochemical behaviour of the compound **8** was studied The irradiation of a 10^{-3} M solution of **8** in aromatic solvents gave high yields of **9** The irradiation of **8** in ethereal or amine solution quantitatively gave **10** The comparison of reaction rates and quantum yields in different solvents gave results in agreement with the hypothesis of an exciplex formation

In the past twenty years the photochemistry of furan has been extensively studied [1] Furan and alkylfurans **1** react with aldehydes or ketones in the Paternò–Büchi reaction[2] giving **2** Furan derivatives also undergo photoisomerisation to a valence tautomer of type **3** [3]



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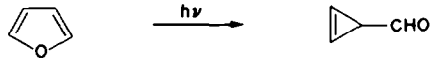


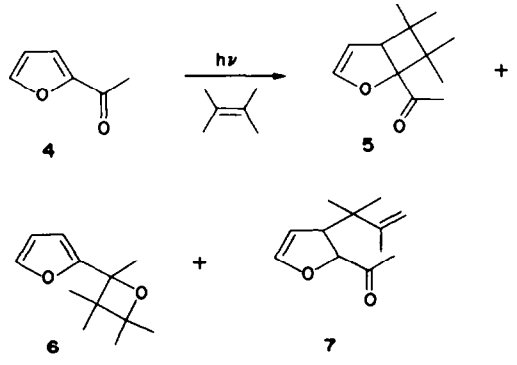
1 3

This transient intermediate, isolated only with 2,5-di-t-butylfuran and 2,3,5-tri-t-butylfuran, rapidly decomposes *via* decarbonylation or reacts with various trapping agents such as MeOH, $PrNH_2$ or furan itself giving interesting products Besides occurring with furan and alkyl-furans, this reaction has also been described with 2-furan-carboxyaldehyde and 2-cyanofuran Photochemical reactions of 2-methoxy-, 2-acetoxy- and 2-nitro-furans, on the other hand, furnish butenolides in high yields [4] Furans also undergo (2+2)-[5] and (2+4)-cycloadditions with olefinic systems, while it can react also with benzene *via* an exciplex [6]

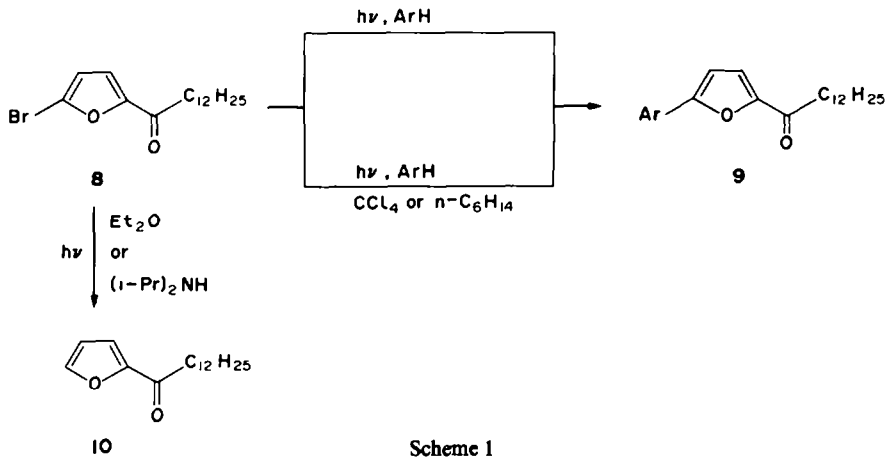
Most of the studies on the photochemical behaviour of furan have been accomplished by using furan itself or very simple derivatives There is little data available on the photochemistry of furans containing one or more additional chromophores It is known that 2- and 3-acetylfuran are not particularly reactive towards photochemical reactions in fact, the only known reaction of 2-acetylfuran **4**, irradiated in the presence of an excess of 2,3-dimethyl-2-butene, gave **5** (38%), **6** (8%), and **7** (7%) [7] On the other hand, 3-acetyl- or 3-benzoylfuran do not react under the same conditions [8]

In this paper we describe the first results on the photochemical reactivity of 5-bromo-2-furyl ketones

This research stems from our studies on the reactivity of furans and their usefulness as synthetic key-intermediates [9] In particular, we reported an original synthetic route leading to 5-bromo-2-furyl ketones, and we pointed out the capability of this substrate to undergo nucleophilic substitutions at the 5-position [10]



4 5 6 7



Scheme 1

RESULTS AND DISCUSSION

As starting material we utilised 5-bromo-2-furyl ketone **8**, which was synthesised as described elsewhere [10–13]

The irradiation of **8**, in benzene solution in a quartz tube with a 500 W high pressure mercury arc, furnished, in high yield, a product which exhibited NMR spectrum with absorptions at δ 7 63 (m, 2H), 7 24 (m, 3H), 6 98 (d, 1H, J = 4 Hz), 6 55 (d, 1H, J = 4 Hz) and 2 74 (t, 2H, J = 7 Hz), while IR spectrum showed a strong absorption at 1674 cm^{-1} Furthermore, the mass spectrum revealed that the product had lost bromine, in agreement with the observed evolution of HBr from the reaction mixture All these data led to the identification of the reaction product as 1-(5-phenyl-2-furyl)-n-tridecan-1-one **9** (Scheme 1)

It is noteworthy that this conversion represents an effective synthetic methodology since only few syntheses are available for the preparation of simple phenylfurans [12 14]

The reaction had to be performed under nitrogen atmosphere since photolysis in presence of oxygen resulted in decomposition of **8** and phenol formation, presumably by reaction of the triplet state of benzene with oxygen [15] This behaviour (the action of oxygen as scavenger) indicated that the reaction proceeded *via* a triplet state or free radicals

The conversion **8** → **9** can be conveniently extended to other volatile aromatic substrates as described in Table 1

In order to broaden the synthetic utility of the reaction, we tried to utilize solvents where **8** was photochemically inactive Carbon tetrachloride and n-hexane in Pyrex seemed to have this feature The results are summarised in Scheme 1 and Table 2 As clearly shown in this table, the use of CCl_4 or n-hexane as solvents involves longer times and higher reaction temperature In spite of the lower yields of **9**, however, this methodology represents an important improvement and a route to new products (Table 3)

Table 1 Photolysis of **8** without co-solvent

Entry	Solvent ArH	Reaction time (hr)	Product	Ar	Yield % GLC	Yield % Isolated
1	Benzene	4 10	**9a**	Phenyl	94	84
2	Toluene	3 50	**9b**	2-Tolyl	93	42
			9c	4-Tolyl		38
3	Furan	5 25	**9d**	2-Furyl	93	80
4	2-Methyl-furan	4 50	**9e**	5-Methyl-2-furyl	93	73

Table 2 Photolysis of **8** with co-solvent

Entry	Co-solvent	ArH	Reaction time (hr)	Temp (°)	Product	Ar	Yield[a] %
1	CCl_4	Benzene	6	80	**9a**	Phenyl	41
2	n-Hexane	Naphthalene	4	80	**9f**	2-Naphthyl	54
3	CCl_4	Anisole	6	75	**9g**	*o*-Methoxy-phenyl	29
					9h	*p*-Methoxy-phenyl	31
4	CCl_4	*p*-Xylene	7	70	**9i**	2,5-Dimethyl-phenyl	50
5	CCl_4	*m*-Xylene	6	80	**9j**	2,4-Dimethyl-phenyl	55

[a] All the yields refer to isolated chromatographically pure products

Table 3 Physical data of the compounds **9**

Compound	m p (°)	MS M^+ (*m/e*)	Elemental analysis C (Calc)	Elemental analysis H (Calc)	IR ν_{max} (cm^{-1})	NMR δ
9a	39–41	340	81 17 (81 13)	9 50 (9 47)	1674	7 63 (m, 2H) 7 24 (m, 3H) 6 98 (d, 1H, J = 4 Hz) 6 55 (d, 1H, J = 4 Hz) 2 74 (t, 2H, J = 7 Hz)
9b	53–54	354	81 27 (81 31)	9 71 (9 67)	1665, 1566 1460	7 48 (m, 1H) 6 97 (m, 4H) 6 30 (d, 1H, J = 4 Hz) 2 70 (t, 2H, J = 7 Hz) 2 47 (s, 3H)
9c	72–74	354	81 29 (81 31)	9 65 (9 67)	1663, 1588 1569, 1480	7 43 (d, 2H, J = 8 Hz) 6 98 (d, 2H, J = 8 Hz) 6 92 (d, 1H, J = 4 Hz) 6 48 (d, 1H, J = 4 Hz) 2 72 (t, 2H, J = 7 Hz) 2 32 (s, 3H)
9d	58–59	330	76 28 (76 33)	9 19 (9 15)	1676, 1632 1510, 1443 1008	7 30 (m, 1H) 6 97 (d, 1H, J = 4 Hz) 6 61 (d, 1H, J = 4 Hz) 6 46 (d, 1H, J = 4 Hz) 6 33 (dd, 1H, J_1 = 4 Hz, J_2 = 2 Hz) 2 72 (t, 2H, J = 7 Hz)
9e	74–75	344	76 44 (76 40)	9 34 (9 36)	1672, 1633 1460, 1018	7 03 (d, 1H, J = 4 Hz) 6 52 (d, 1H, J = 4 Hz) 6 42 (d, 1H, J = 4 Hz) 5 97 (d, 1H, J = 4 Hz) 2 72 (t, 2H, J = 7 Hz)
9f	45–46	390	83 00 (83 03)	8 79 (8 77)	1668, 1565 1458	8 38 (m, 1H) 7 84 (m, 3H) 7 55 (m, 2H) 7 33 (d, 1H, J = 4 Hz) 7 32 (s, 1H) 6 83 (d, 1H, J = 4 Hz) 2 87 (t, 2H, J = 7 Hz)
9g	41–43	370	77 83 (77 80)	9 20 (9 25)	1672, 1602 1510, 1487 1462, 1449 1243, 1028	8 00 (m, 1H) 7 41 (m, 3H) 7 27 (d, 1H, J = 4 Hz) 7 07 (d, 1H, J = 4 Hz) 3 91 (s, 3H) 2 82 (t, 2H, J = 7 Hz)
9h	50–52	370	77 78 (77 80)	9 24 (9 25)	1672, 1610 1472, 1250 1032	7 65 (d, 2H, J = 16 Hz) 7 15 (d, 1H, J = 4 Hz) 6 87 (d, 2H, J = 16 Hz) 6 58 (d, 1H, J = 4 Hz) 3 80 (s, 3H) 2 79 (t, 2H, J = 7 Hz)
9i	63–65	368	81 50 (81 47)	9 83 (9 85)	1676, 1458	7 28 (m, 1H) 6 87 (m, 3H) 6 40 (d, 1H, J = 4 Hz) 2 72 (t, 2H, J = 7 Hz) 2 41 (s, 3H) 2 30 (s, 3H)
9j	67–69	368	81 45 (81 47)	9 86 (9 86)	1673, 1360 874, 848 820	7 45 (m, 1H) 6 96 (m, 3H) 6 43 (d, 1H, J = 4 Hz) 2 73 (t, 2H, J = 7 Hz) 2 47 (s, 3H) 2 30 (s, 3H)

Table 4 Effect of the temperature on the photolysis of **8**

Entry	Filter	Temp (°)	k 10^2 s^{-1}
1	—	64	92±01
2	Pyrex	39	23±01
3	—	76	138±03

Careful studies were carried out in order to elucidate the mechanism of the reaction First of all, experimental data could establish that it took place *via* $n \rightarrow \pi^*$ transition to the lowest excited singlet state In fact, the UV spectrum of **8** shows a strong absorption (log ε 4 23) at 248 nm (K band) and a very weak one at 350 nm (R band) Pyrex can filter the K band but the photolysis in either Pyrex or in quartz showed the same rate at the same temperature (39°) Furthermore, when carried out at different temperatures (either in Pyrex or quartz) the reaction followed first order or pseudo-first order kinetics having different values of k (Table 4) These values fitted the Arrhenius equation (Fig 1), allowing to calculate $\Delta H^{\neq} \sim 11$ Kcal/mol and $\Delta S^{\neq} \sim -55$ cal/mol The $\Delta H^{\neq}$ value could be explained assuming that (a) the rate determining step of the reaction does not involve any fission of a chemical bond or (b) the fission of a chemical bond (i e C—Br) occurs in the lowest excited triplet state of the molecule The latter statement, however, is not in agreement with the $\Delta S^{\neq}$ negative value

We have also studied the kinetic behaviour of **8** irradiated in a *ca* 5×10^{-3} M solution of one of four solvents (benzene, toluene, chlorobenzene, and anisole) at 28° The results, obtained by GLC and summarized in Fig 2, showed that all the reactions follow a first order kinetics with a k value of $(2\,7 \pm 0\,1) \times 10^{-2}$ (benzene), $(6\,6 \pm 0\,2) \times 10^{-2}$ (toluene), $(3\,2 \pm 0\,1) \times 10^{-2}$ (anisole), and, finally $(4\,0 \pm 0\,3) \times 10^{-2}$ s^{-1} (chlorobenzene) These data can not be explained assuming the homolytic fission of the C—Br bond, but they can be rationalized assuming the formation of an electron transfer exciplex,[16–20] a hypothesis which has been frequently utilized in the furan field [5e 21] In this case it

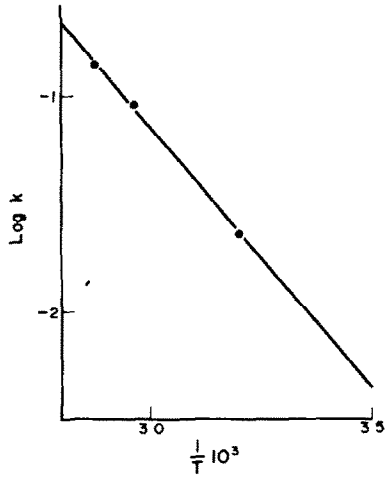


Fig. 1 Arrhenius plot for the photolysis of **8**

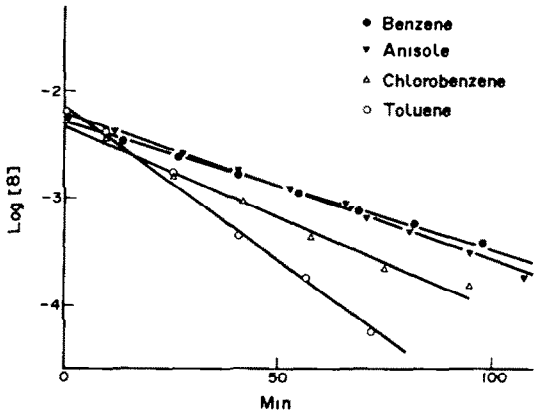
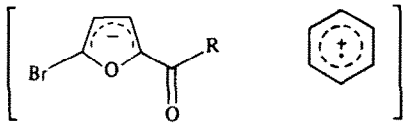


Fig. 2 Kinetic behaviour of **8** in four solvents

would imply the formation of the exciplex **11** which can evolve to the product **9** *via* a radical coupling with the subsequent elimination of HBr Electron transfer



11

processes follow the Weller Eq (1),

$$\Delta G = E_{D/D^+} - E_{A/A^-} - h\nu^\circ - e^2/\varepsilon a \qquad (1)$$

where E_{D/D^+} is the oxidation potential of the donor (in general correlated with its ionization potential IP[22]) and E_{A/A^-} is the reduction potential of the acceptor This equation can be simplified to Eqs (2) and (3) [18]

$$-\ln k = \beta \cdot IP \qquad (2)$$

$$\ln\left(\frac{1}{\Phi} - 1\right) = \beta \cdot IP \qquad (3)$$

The formation of radical pairs was confirmed by the fact that the irradiation in a Pyrex flask of **8** in Et_2O (IP 9 6 eV[23]) for 1 hr, and in diisopropylamine (IP 7 73 eV[23]) for 10 min, quantitatively furnished 2-furyl ketone **10** (Scheme 1), while the irradiation in carbon tetrachloride (IP 11 47 eV[23]) or chloroform (IP 11 42 eV[23]) under the same conditions was unsuccessful

The correlation, through Eq (3), between the quantum yields and the ionization potentials of ArH (benzene, 9 24, toluene, 8 82, anisole, 8 21, chlorobenzene, 9 07 eV[23]) lead to the plot shown in Fig 3, which clearly showed that while benzene, toluene and chlorobenzene fit Eq (3), anisole exhibited an anomalous behaviour

In conclusion, although some mechanistic aspects of the conversion **8** → **9** are not fully clarified (further investigations are in progress), it represents a new synthetic and improved method, it could replace other routes at present employed, for the simplicity of the procedure and the excellent yields

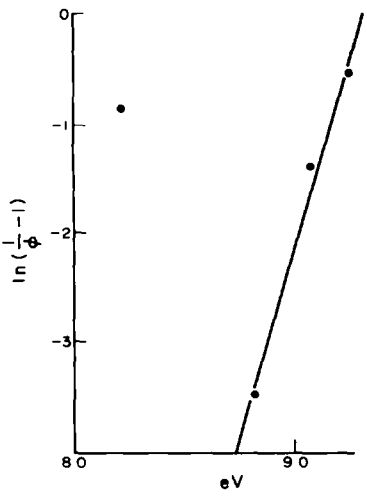


Fig. 3 Correlation between the quantum yields of the formation of **9** and the ionization potential of ArH (Eq 3)

EXPERIMENTAL

M ps were obtained with a Kofler block and are uncorrected NMR spectra were recorded with a Perkin–Elmer R-32, a Varian EM-360 or a Bruker WP-80 SY, using CCl_4 (**9a**, **9b**, **9c**, **9d**, **9e**, **9i**, **9j**, **10**) or $CDCl_3$ (**9f**, **9g**, **9h**) as solvents with TMS as internal standard IR spectra were obtained on Perkin–Elmer 257 and 457 spectrometers using 1% solns in CCl_4 (**9a**, **9d**, **9e**, **9g**, **9h**, **9i**) or $CHCl_3$ (**9b**, **9c**, **9f**) or CS_2 (**9j**) Mass spectra were obtained on an AEI MS-12 instrument at 70 eV, by using direct insertion at source temp 150° UV spectra were recorded with a Varian DMS-90 Elemental analyses were obtained with a Carlo Erba Elemental Analyzer 1106 Commercial Merck silica gel and alumina were used for column chromatography Carlo Erba precoated silica gel plates were used in TLC Kinetic data were obtained by using direct gas chromatographic analyses of the reaction mixtures The solutions were maintained at constant temp by using GFL 5001 thermostatic bath GLC analyses were carried out on a Hewlett–Packard 5880A instrument, using flame ionization detection, 20 in stainless-steel column 2% OV 101 on 100/120 Chromosorb W-HP or 6 ft 5% Carbowax 20 M on 80/100 Chromosorb W-HP, oven temp 150–250°, rate 10°/min, and N_2 as carrier gas

Compounds **9**

General procedure without co-solvent The soln of **8** (750 mg) in ArH (300 ml) was outgassed with N_2 (1 hr) and then irradiated with a 500 W Helios Italquartz high pressure mercury arc under N_2 When the reaction was completed (Table 1), the mixture was diluted with Et_2O and the soln was washed with brine The neutral extracts were dried over Na_2SO_4 The removal of the solvent yielded a crude product that was chromatographed on SiO_2 Elution with n-hexane–Et_2O 9 1 gave the pure product (Table 3)

Compounds **9**

General procedure with co-solvent **8** (200 mg), dissolved in 4 ml of CCl_4 and 4 ml of ArH, was outgassed with N_2 (30 min) and irradiated with a 500 W Helios Italquartz high pressure mercury arc equipped with a Pyrex filter (Table 2). When the reaction was completed, the removal of the solvent yielded a crude product that was chromatographed on SiO_2 Elution with C_6H_6 gave the pure product (Table 3)

1-(2-*Furyl*)-*n-tridecan*-1-*one* **10** The soln of **8** (100 mg) in anhyd Et_2O or $(i\text{-}Pr)_2NH$ (50 ml) was outgassed with N_2 (1 hr) and irradiated with a 400 W medium pressure mercury arc equipped with a Pyrex filter for 1 hr (or 10 min when the reaction was carried out in $(i\text{-}Pr)_2NH$) under N_2 The removal of the solvent yielded a crude product that was chromatographed on SiO_2 Elution with petroleum ether–Et_2O 9 1 gave 77 mg (100%) of pure **10** ^{1}H-NMR (CCl_4) δ 7 35 (m 1H) 6 93 (d 1H, J = 3 Hz), 6 32 (dd, 1H, J_1 = 3 Hz, J_2 = 2 Hz), 2 70 (t, 2H, J = 7 Hz) MS, *m/e* 264 (M^+)

Quantum yields The quantum yields were determined in a Rayonet Chamber Reactor, using a lamp whose output centred at 350 nm, with a rotating tube holder Decafluorobenzophenone-decafluorobenzhydrol[25] was used as actinometer The measurements were carried to $\leq$5% conversion and the formation of **9** was determined by GLC

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