PHOTOCHEMISTRY OF α-FLUOROCYCLOALKANONES AND α-BROMO-α-FLUOROCYCLOALKANONES

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SUMMARY

Uv irradiation of a cyclohexane solution of 2-fluoro-1-indanone, 2-fluoro-1-tetralone, or 2-fluoro-1-benzosuberone resulted in the formation of a radical product (1-indanone, 1-tetralone, or 1-benzosuberone), and the degree of conversion depended on the ring size of the cycloalkanone. On the other hand, both radical as well as ionic products were formed when 2-bromo-2-fluoro derivatives of 1-indanone, 1-tetralone, or 1-benzosuberone were irradiated.

INTRODUCTION

The photochemistry of α-halo cycloalkanones includes different types of photoprocesses, such as α-cleavage [1], photoelimination [2], hydrogen abstraction by α-keto radicals [3], and rearrangement [4]. We have already found that uv irradiation of a cyclohexane solution of 2-halo-1-indanone and 2-halo-1-tetralone (i.e., chloro, bromo, iodo) [5,6] results in competition between radical and ionic photoprocesses, the nature of the photochemical carbon-halogen bond cleavage depending on the halogen atom bonded and the ring size of the ketone. On the other hand, α-cleavage of the carbon-carbon bond took place when 2-fluoro cyclohexanone [1] was irradiated in methanol, and a fluoro substituted ester was formed as the sole product.

RESULTS AND DISCUSSION

We found it instructive to study the influence of the phenyl ring, which is in a conjugate position to the carbonyl group, on the photobehaviour of the C-F

bond in fluoro cycloketones, and 2-fluoro-1-indanone (7), 2-fluoro-1-tetralone (8), and 2-fluoro-1-benzosuberone (9) were chosen as substrates.

A 15-hour irradiation of 2-fluoro-1-indanone in the presence of an equivalent amount of triethylamine (TEA) in cyclohexane solution at λ = 253.7 nm resulted in 32% conversion of the starting ketone, and 1-indanone was formed as the sole product, as determined by ^{1}H nmr spectroscopy and glc analysis of the crude reaction mixture (Scheme 1, Table 1). The formation of the reduction product can be explained by hydrogen abstraction by the α-keto radical formed by homolytic carbon-fluorine bond cleavage.
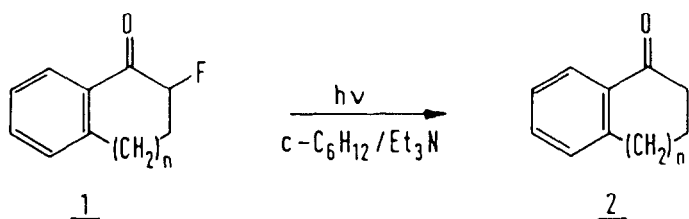
$$\text{1} \xrightarrow[c-C_6H_{12}/Et_3N]{h\nu} \text{2}$$

n = 0, 1, 2

scheme 1

TABLE 1

The Effect of the Ring Size and the Halogen Atom on the Nature of the Photochemical Carbon-Halogen Bond Cleavage[a]

n	HALOGEN ATOM	CONVERSION %	RELATIVE YIELDS OF PRODUCTS			PRODUCTS RATIO[b]
			1	2	4	
0	F	32		100		1
	Br,F	10	trace	100		1
1	F	40		100		1
	Br,F	40	38	trace	62	0.38
2	F	80		100		1
	Br,F	87	40		60	0.4

[a] Reaction conditions: t= 15 hours, T= 30°C, λ = 253.7 nm.

[b] Radical vs radical and ionic

In order to determine the influence of the ring size of the cycloketone on the nature of the photochemical carbon-fluorine bond fission, we also studied the phototransformation of 2-fluoro-1-tetralone and 2-fluoro-1-benzosuberone under the same reaction conditions. In both cases only the reduction product (1-tetralone and 1-benzosuberone) was obtained (Scheme 1), while the degree of conversion of the starting fluoro ketone strongly depended on the ring size of the cycloalkanone and was 40% in the case of 2-fluoro-1-tetralone, and 80% in the case of 2-fluoro-1-benzosuberone (Table 1).

It is known from the literature that photoreduction of carbonyl compounds by amines [10] differs from photoreduction of these compounds by alcohols, and that in the case of ketones where an α-hydrogen is not present, amines act as quenchers only. Photoreduction by primary amines was similar or faster than by 2-propanol, about half as fast by secondary amines, while tertiary amines showed low reactivity.

Hence, we would like to determine the influence of the concentration of added triethylamine on the efficiency of the photochemical carbon-fluorine bond fission, and to measure the quantum yields of the reduction of 2-fluoro-1-tetra-lone to 1-tetralone in the presence of different amounts of triethylamine. From the results obtained (Table 2) it is evident that an increase in the amount of tri-ethylamine resulted in a decreased quantum yield, while there was no effect when the amount of triethylamine was greater than the equivalent.

TABLE 2

The Effect of Triethylamine on the Quantum Yield of Reduction of 2-Fluoro-1-Tetralone to 1-Tetralone[a]

RATIO OF 2-FLUORO-1-TETRALONE : TEA			ϕ (reduction)[mol Einstein^{-1}]
1.00	:	0.00	0.040 ± 0.003
1.00	:	0.25	0.023 ± 0.004
1.00	:	0.50	0.016 ± 0.002
1.00	:	0.75	0.015 ± 0.001
1.00	:	1.00	0.015 ± 0.001

[a] Concentration of 2-fluoro-1-tetralone: 0.05 mol/l, T= 14°C, λ = 253.7 nm, light intensity: 1.06 . 10^{16} photons/ml s

We further studied the influence of the introduction of another α -halogen atom into the α-fluoro cycloketone on the nature of the carbon-halogen bond cleavage, and for this purpose, the following substrates were chosen: 2-bromo-2-fluoro-1-indanone, 2-bromo-2-fluoro-1-tetralone, and 2-bromo-2-fluoro-1-benzosuberone. The above mentioned compounds were prepared by bromination of the corresponding 2-fluoro cycloalkanones in CS_2. In all three cases, 2-bromo-2-fluoro-cycloalkanones formed as the sole products (Scheme 2).


n = 0,1,2
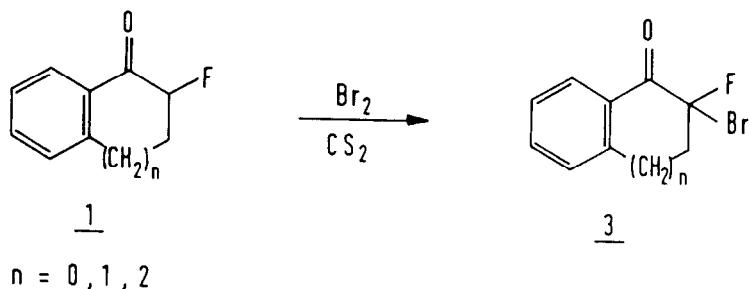
scheme 2

A 15-hour irradiation of a cyclohexane solution of 2-bromo-2-fluoro-1-indanone in the presence of a two fold excess of triethylamine at λ = 253.7 nm resulted in 10 percent conversion of the starting ketone, and besides 1-indanone, only a trace amount of 2-fluoro-1-indanone was formed (Scheme 3, Table 1), which was determined by ^1H and ^{19}F nmr spectroscopy and analytical glc.

Uv irradiation of a cyclohexane solution of 2-bromo-2-fluoro-1-tetralone under the same reaction conditions led to 40 percent conversion of the starting ketone. ^{19}F nmr of the crude reaction mixture showed in addition to the signal at δ = -141.3 ppm, corresponding to the starting compound, signals at δ = -115.3 ppm (dd, J= 10Hz, 6 Hz) and -192 ppm (dm) in a relative ratio of 62:38. The signal at lower field corresponded to 2-fluoro-1-naphthol [12], while the signal at δ = -192 ppm with a coupling constant J= 47.5 Hz corresponded to 2-fluoro-1-tetralone (Scheme 3, Table 1). By analytical glc, we determined that a trace amount of 1-tetralone was also formed. The formation of 2-fluoro-1-tetralone can be explained by hydrogen abstraction by the α -keto radical formed by a homolytic carbon-bromine bond cleavage, which could be transformed in the next radical step to 1-tetralone, while 2-fluoro-1-naphthol represents a tautomeric

form of the initial ionic product formed by elimination of the proton from an α -keto carbocation via the ionic reaction pathway (Scheme 4).
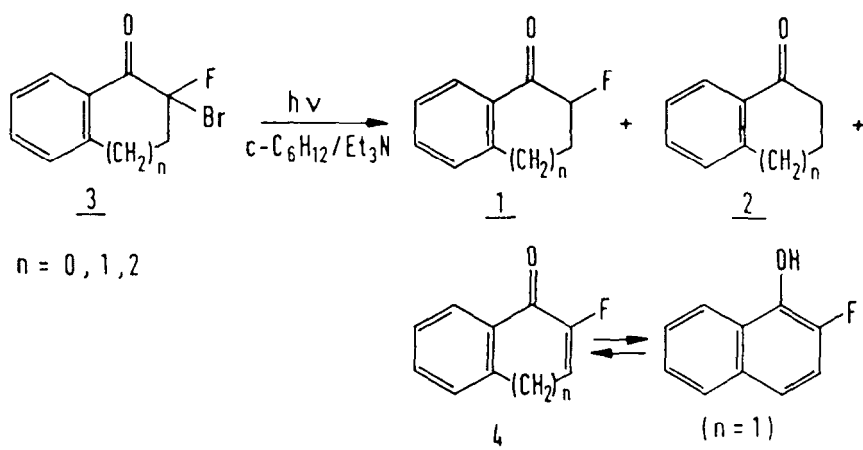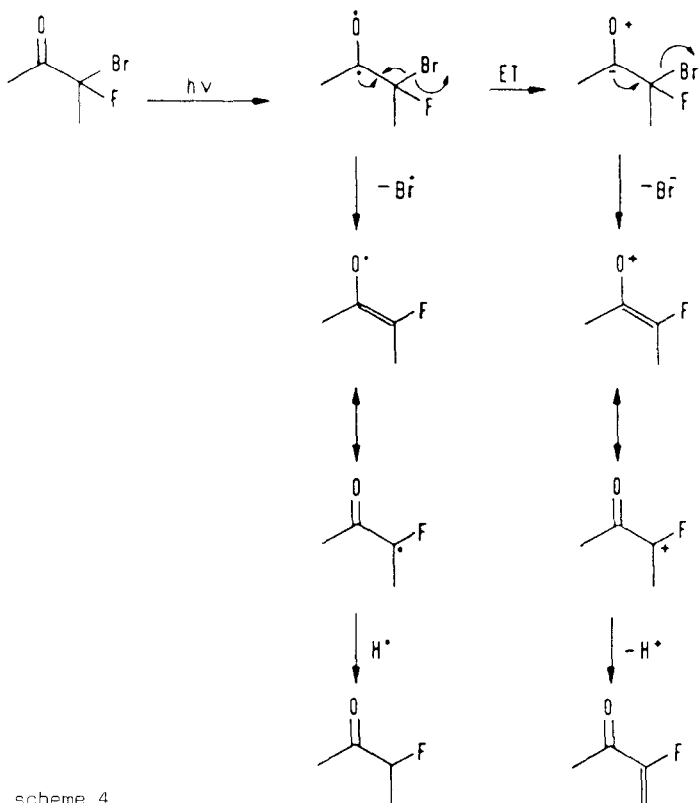

scheme 3

Irradiation of 2-bromo-2-fluoro-1-benzosuberone resulted in 87 percent conversion, with 1-benzosuberone and 2-fluoro-2-benzosuberen-1-one formation in a 2:3 ratio (Scheme 3, Table 1), which was determined by ^{1}H and ^{19}F nmr spectroscopy and analytical glc. The crude reaction mixture was separated by preparative tlc and glc and the structures of the products were determined on the basis of their spectroscopic data. The ^{19}F nmr spectrum of compound 4 showed a signal at δ = -116.67 ppm (dt) with coupling constants J= 21 Hz and 4 Hz, while besides other signals in ^{1}H nmr, the signal at δ = 6.50 ppm (dt) with coupling constants J= 21 Hz and 5 Hz also appeared, corresponding to the olefinic hydrogen atom.

Under the mentioned conditions, i.e. in the presence of di or triethylamine, 2-bromo-2-fluoro-1-benzosuberone was stable when not irradiated and did not transform to 2-fluoro-2-benzosuberen-1-one.

1-Benzosuberone formation corresponds to the radical reaction pathway, while 2-fluoro-2-benzosuberen-1-one is formed via the ionic reaction pathway from the corresponding α -keto carbocation (Scheme 4).

From the results obtained on the irradiation of α -bromo- α -fluoro cyclo- ketones, we can conclude that carbon-bromine bond cleavage takes place first, leading to radical as well as cationic intermediates. The nature of the inter-

mediates depends upon the ring size of the cycloketone, radical intermediates being the sole products in the case of a five membered ketone, while in the case of six and seven membered rings both radical and ionic intermediates were observed.

scheme 4

EXPERIMENTAL

Preparative experiments were carried out with a Rayonet Model RPR 100 with 253.7 nm lamps. Ir spectra were recorded using a Perkin Elmer 727 B spectrometer and ^{1}H and ^{19}F nmr spectra (frequencies 60 MHz and 56.45 MHz respectively) by a Varian EM-360 spectrometer with TMS or CCl_3F as internal reference. Mass spectra and high resolution measurements were taken on a CEC 21-110 spectrometer. Tlc was carried out on Merck PSC Fertigplatten F 254 and glc on a Varian Aerograph, Model 3700. Melting points were determined on a Kofler apparatus and are uncorrected.

2-Fluoro-1-indanone [7], 2-fluoro-1-tetralone [8], and 2-fluoro-1-benzosuberone [9] were prepared by fluorination of the corresponding enol acetates with XeF_2. Solvents were purified by known procedures [11].

General Procedure for Irradiation of 2-Fluoro-Cycloalkanones

An 18-ml, 0.056 M cyclohexane solution of 2-fluoro-1-indanone, 2-fluoro-1-tetralone, or 2-fluoro-1-benzosuberone in the presence of an equivalent amount of triethylamine was irradiated in a quartz tube for 15 hours, the solvent was evaporated in vacuo, the crude reaction mixture was analysed by ^1H and ^{19}F nmr spectroscopy and analytical glc (OV 17 (5%) on Chromosorb W AW 80/100), and the irradiation products outlined in Scheme 1 were isolated by preparative gas chromatography (OV 17 (15%) on Chromosorb W AW). Their spectral properties agreed with those of authentic samples.

Determination of Quantum Yields

Quantum yields were measured by using a ferioxalate actinometer and in each experiment the amount of transmitted light was measured. Quartz cuvettes were filled with 5 ml of a 0.05 M cyclohexane solution of 2-fluoro-1-tetralone and the corresponding amounts of triethylamine, thermostatted by external cooling, and the temperature of the solution measured. The light source was an RPR 253.7 nm without filters. The products were analyseo by analytical glc. Irradiation times were chosen so that conversion of 2-fluoro-1-tetralone was not greater than 10% of its initial concentration. Each quantum yield determination was repeated at least three times and the average data are presented in Table 2. The concentrations of reagents, light intensity and temperature are also listed in Table 2.

Preparation of 2-Bromo-2-Fluoro Cycloalkanones

1.3 Mmol of 2-fluoro-1-indanone, 2-fluoro-1-tetralone, or 2-fluoro-1-benzosuberone was dissolved in 5 ml of freshly distilled CS_2, 416 mg (2.6 mmol) of bromine was added, and the reaction mixture stirred at room temperature for 3 hours, diluted with 10 ml of CS_2, the solution washed with 50 ml of $NaHSO_3$ and 50 ml of $NaHCO_3$ solution, the organic phase dried with Na_2SO_4 and the solvent evaporated in vacuo.

2-Bromo-2-Fluoro-1-Indanone (nc)

The crude reaction product obtained was crystallized from n-pentane and
0.23 g (78%) of 2-bromo-2-fluoro-1-indanone was isolated (mp= 74-77°C).

Spectroscopic data: ^{1}H nmr (CDCl$_3$) δ = 3.7-4.2 (2H, m, H-3), 7.2-7.9
ppm (4H, m, aromatic H's), ^{19}F nmr: δ -123.33 ppm (1F, dd, J$_{F,H}$= 13 Hz, 8
Hz), mass spectra m/z (relative intensity): M$^+$+2 230(18), M$^+$ 228(18), 149(100),
129(15), 121(11), 120(14), 101(39), 75(14), 50(14). Found m/z 227.9583, calcd.for
C$_9$H$_6$BrFO: M, 227.9586.

2-Bromo-2-Fluoro-1-Tetralone (nc)

The crude reaction product obtained was crystallized from n-pentane and
0.225 g (71%) of 2-bromo-2-fluoro-1-tetralone was isolated (mp= 78-80°C).

Spectroscopic data: ^{1}H nmr (CDCl$_3$) δ = 2.5-3.5 (4H, m, H-3, H-4), 7.1-
8.1 ppm (4H, m, aromatic H's), ^{19}F nmr: δ = -141.3 ppm (1F, m), mass spectra
m/z (relative intensity): M$^+$+2 244(20), M$^+$ 242(20), 163(22), 162(15), 133(20),
118(100), 115(24), 90(40), 89(12), 62(12). Found m/z 241.9746, calcd. for
C$_{10}$H$_8$BrFO: M, 241.9743.

2-Bromo-2-Fluoro-1-Benzosuberone (nc)

The crude product obtained was purified by column chromatography (eluted
by chloroform : petrol ether 4:1) and 0.203 g (61%) of oily 2-bromo-2-fluoro-1-
benzosuberone was isolated.

Spectroscopic data: ^{1}H nmr (CDCl$_3$) δ = 1.8-3.0 (6H, m, H-3, H-4, H-5),
7.0-7.6 ppm (4H, m, aromatic H's), ^{19}F nmr: δ = -103 ppm (1F, dd, J$_{F,H}$= 12
Hz, 11 Hz), mass spectra (relative intensity): M$^+$+2 258(18), M$^+$ 256(18), 178(14),
177(100), 175(14), 149(51), 131(47), 129(52), 128(18), 104(33), 103(26), 91(16), 90
(20), 78(13), 77(31), 63(21), 51(26). Found m/z 255.9896, calcd. for C$_{11}$H$_{10}$BrFO:
M, 255.9899.

General Procedure for Irradiation of 2-Bromo-2-Fluoro-Cycloalkanones

15 Ml of a 0.033 M cyclohexane solution of the 2-bromo-2-fluoro derivative
of 1-indanone, 1-tetralone, or 1-benzosuberone were irradiated in a quartz tube in
the presence of 1 mmol (101 mg) of triethylamine for 15 hours, the solvent evapo-
rated in vacuo, the crude reaction mixture analysed by ^{1}H and ^{19}F nmr spectro-
scopy and analytical glc (OV 17 (5%) on Chromosorb W AW 80/100), and the

product resulting from the irradiations outlined in Scheme 3, were isolated by preparative glc (OV 17 (15%) on Chromosorb W AW) or tlc (SiO_2, mobile phase: chloroform : petrol ether 4:1), and identified on the basis of their spectroscopic data and comparison with authentic samples.

2-Fluoro-2-Benzosuberen-1-One (nc)

Oily product, spectroscopic data: ^1H nmr ($CDCl_3$) δ = 2.7 (4H, m, H-4, H-5), 6.50 (1H, dt, J= 21 Hz, 5 Hz, H-3), 7.47 ppm (4H, m, aromatic H's), ^{19}F nmr: δ= -116.67 ppm (1F, dt, J= 21 Hz, 4 Hz), mass spectra m/z (relative intensity): M^+ 176(100), 175(14), 148(42), 147(47), 146(36), 133(36), 131(28), 129(42), 127(21), 115(17), 104(35), 103(19), 89(22), 77(25), 63(22), 51(28). Found m/z 176.0639, calcd. for $C_{11}H_9FO$: M, 176.0637.

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