PHOTOCHEMICAL REDUCTION OF A C—F BOND
IN DERIVATIVES OF 2,3,3-TRIFLUOROCARBOXYLIC ACIDS*

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Photochemically initiated reduction of C—F bond in methyl 3-(2-tetrahydrofuryl)-2,3,3-trifluoropropionate (*I*), methyl 3-methoxy-2,3,3-trifluoropropionate (*II*) and 4,4-dimethyl-2,3,3--trifluoro-4-butanolide (*III*) was carried out in 2-propanol, tetrahydrofuran and 1,3-dioxolane. The reduction takes place at the C—F bond in the α-position relative to carbonyl group. The reducing power of solvent decreases in the order given above, the reactivity decreases in the order *III* > *II* > *I*. The reaction mechanism is discusssed.
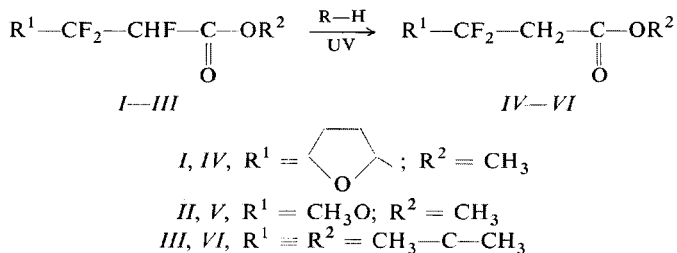
Radical reduction of a carbon–halogen bond in halides or fluoro halides with solvents, capable of donation of the required hydrogen, which is initiated by peroxides[1-4], UV-light[5-9] or [60]Co γ-irradiation[8], was described for carbon–chlorine[1-6,10-13], carbon–bromine[9] and carbon--iodine[7] bonds. To our knowledge the first case of reduction of a carbon–fluorine bond in a photochemically initiated reaction was observed by ourselves in the addition of ethers to methyl trifluoroacrylate[14]. Among the minor products of the addition of tetrahydrofuran to methyl trifluoroacrylate we found a product of reduction of the primarily formed adduct *I* and suggested its structure to be methyl 3-(2-tetrahydrofuryl)-2,3-difluoropropionate.

In order to investigate in more detail photochemical reduction of the C—F bond we chose methyl 3-(2-tetrahydrofuryl)-2,3,3-trifluoropropionate (*I*), methyl 3-methoxy-2,3,3-trifluoropropionate(*II*) and 4,4-dimethyl-2,3,3-trifluoro-4-butanolide(*III*). All the esters *I*−*III* were photochemically reduced with 2-propanol, the ester *I* also with tetrahydrofuran and 1,3-dioxolane. We have found that the C—F bond in compounds *I*−*III* is in all cases reduced at the α-carbon relative to the ester group (Scheme 1). Therefore, a revision of our original suggestion[14] is necessary since the reduction product of the ester *I* is methyl 3-(2-tetrahydrofuryl)-3,3-difluoropropionate (*IV*).

In addition to this derivative (*IV*), UV-irradiation of the ester *I* in tetrahydrofuran affords octahydro-2,2′-bifuran (*VII*) as a side product; after 10 hours the reaction mixture contained 40% of the starting ester *I*, 30% of the reduction product *IV* and 30% of the

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compound *VII*. Photochemical reductions of the derivatives *I—III* with 2-propanol gave the reduction products *IV—VI*, together with pinacolone as the side-product.

$$R^1\text{—}CF_2\text{—}CHF\text{—}\underset{\underset{O}{\|}}{C}\text{—}OR^2 \xrightarrow[\text{UV}]{\text{R—H}} R^1\text{—}CF_2\text{—}CH_2\text{—}\underset{\underset{O}{\|}}{C}\text{—}OR^2$$

$$I\text{—}III \qquad\qquad\qquad IV\text{—}VI$$

$$I, IV, \ R^1 = \langle\text{—}O\text{—}\rangle ; \ R^2 = CH_3$$
$$II, V, \ R^1 = CH_3O; \ R^2 = CH_3$$
$$III, VI, \ R^1 = R^2 = CH_3\text{—}C\text{—}CH_3$$

SCHEME 1

After UV-irradiation of the methoxypropionate *II* in 2-propanol for 10 hours the gas–liquid chromatographic analysis of the reaction mixture showed 50% of the starting ester *II*, 42% of methyl 3-methoxy-3,3-difluoropropionate (*V*) and 8% of pinacolone. Analogously, the reduction of 4,4-dimethyl-2,3,3-trifluoro-4-butanolide (*III*) with 2-propanol afforded after 10 hours 40% of the starting lactone (*III*), 55% of 4,4-dimethyl-3,3-difluoro-4-butanolide (*VI*) and 5% of pinacolone. Since during the preparative gas–liquid chromatography the lactone *VI* was partially dehydrofluorinated to 4,4-dimethyl-3-fluoro-2-buten-4-olide (*VIII*), we used for analytical purposes the butenolide *VIII* which was obtained by dehydrohalogenation of the lactone *VI* by heating with anhydrous potassium fluoride[15].

Pinacolone and octahydro-2,2'-bifuran (*VII*) arise as the result of transformations of the solvents during the photochemical reduction. Formation of pinacolone can be explained by reactions of acetone which is, as we have shown earlier[8], the primary oxidation product of 2-propanol and at the same time a measure of the photochemical reduction of the C—Cl bond with this alcohol[8]. It is known[16,17] that acetone reacts with 2-propanol under formation of pinacol when irradiated with UV-light. We have proved that reduction of the compounds *I—III* in 2-propanol affords also hydrogen fluoride in an amount which is equivalent to the amount of acetone. The presence of hydrogen fluoride can cause the rearrangement of pinacol to pinacolone. We tried to explain the formation of octahydro-2,2'-bifuran (*VII*) and the course of the reduction of the compound *I* with tetrahydrofuran on the basis of the following facts: Gas–liquid chromatographic analyses show that in the reaction of the ester *I* with tetrahydrofuran the amount of the dehydro dimer *VII*, present in the product, was at least equivalent to that of the reduction product *IV* and simultaneously also the same amount of hydrofluoric acid was formed. Although it is known that the dehydro dimer *VII* is formed by irradiation of tetrahydrofuran with light[18,19], it can be assumed, in connection with the formation of hydrofluoric acid, that the formation of *VII* is a measure of the C—F bond reduction in the ester *I*. 2-Fluoro-

tetrahydrofuran was not found among the reaction products. Finally, it was not possible to reduce photochemically the compound I in toluene, a solvent which was used as the hydrogen donor in radical reductions of some halides[20,21]. On the basis of these facts we conclude that the first reaction step is the formation of the radical IX from the solvent rather than a homolytic fission of the C—F bond in the ester I (Scheme 2). As a proper reducing agent we regard the hydrogen atom, which arises

SCHEME 2
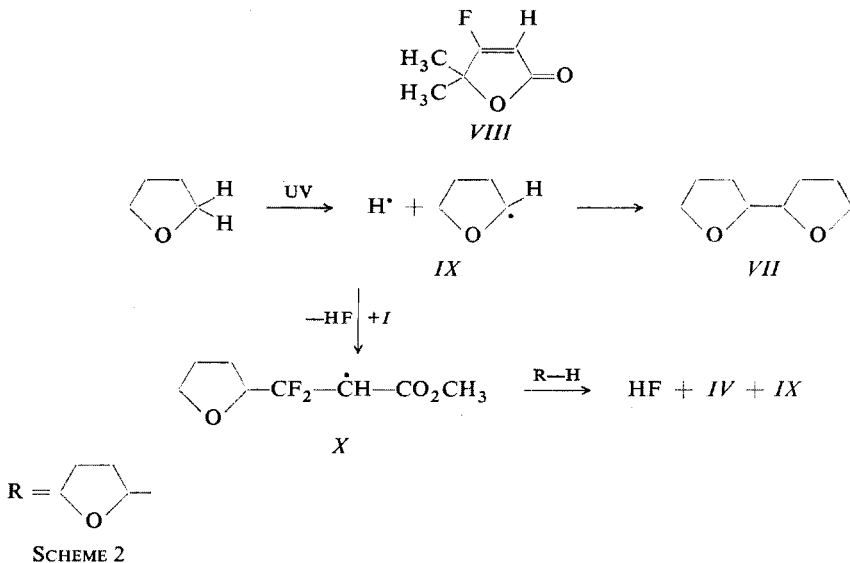
in the formation of the radical IX and which interacts with the ester I to give the radical X and hydrogen fluoride. This radical reacts with a molecule of tetrahydrofuran under formation of a new radical IX which is stabilised by dimerisation to the
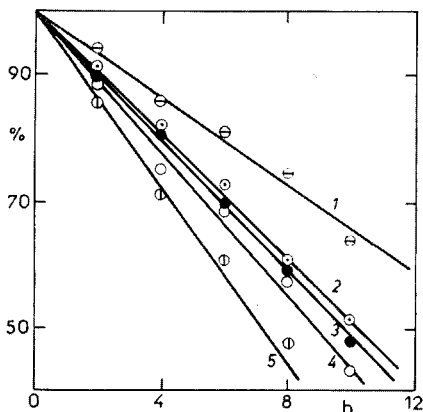

FIG. 1

Time Dependence of the Concentration Decrease of Substrates I—III in the Photochemical Reduction of the C—F Bond

1 I, 1,3-Dioxolane; 2 I, tetrahydrofuran; 3 I, 2-propanol, 4 II, 2-propanol; 5 III, 2-propanol.

dehydro dimer *VII*. We assume an analogous reaction course also in the reaction of the esters *II* and *III* in tetrahydrofuran, 2-propanol and 1,3-dioxolane.

The reducing power of the solvents was determined by studying the rates of reduction of the ester *I*. The decrease in *I* was followed by gas–liquid chromatography using an internal standard (Fig. 1). The following order of reducing powers was found: 2-propanol > tetrahydrofuran > 1,3-dioxolane. Analogously, we tried to compare the relative reactivity of the C—F bond in the esters *I — III* in the photochemical reduction with 2-propanol. The results given in Fig. 1 show that the rate of reduction of the C—F bond with 2-propanol decreases in the order:

$$
\underset{III}{\left.\begin{array}{c} H_3C \\ H_3C \end{array}\right\rangle C \underset{O}{\overset{CF_2-CHF}{\underset{CO}{|}}} } \;>\; \underset{II}{CH_3O-CF_2CHF-CO_2CH_3} \;>\; \underset{I}{\left\langle\!\!\!\bigcirc\!\!\!\right\rangle\!\!-CF_2CHF-CO_2CH_3}
$$

EXPERIMENTAL

Temperature data are uncorrected. Gas–liquid chromatographic analyses were performed on a Chrom 3 (Laboratorní přístroje, Prague) chromatograph equipped with flame ionisation detector; diameter of analytical columns 0·6 cm, diameter of preparative column 1 cm, length 500 cm, carrier gas nitrogen, support Chromaton N-AW-DMCS (Lachema, Brno). IR spectra were taken on a Perkin-Elmer 325 (Bodenseewerk) instrument. Mass spectra were measured on a Gas Chromatograph — Mass Spectrometer LKB 9000 spectrophotometer (Stockholm); single-focus, 70 eV, chromatographic inlet: poly(ethylene glycol adipate) on Chromaton N-AW, 250 . 0·23 cm glass column, carrier gas helium (10 ml/min).

Materials. 1,3-Dioxolane was prepared by the reaction of ethylene glycol with paraformaldehyde in the presence of an ion-exchanging resin[22]. Preparation of methyl 2,3,3-trifluoro-3-(2-tetrahydrofuryl)propionate (*I*) is described in a previous communication[14]. Methyl 2,3,3-trifluoro-3-methoxypropionate (*II*) was prepared[23,24] by the reaction of methyl trifluoroacrylate with methanol in the presence of potassium fluoride (20 minutes at 30°C), yield 84·3%. 4,4-Dimethyl-2,3,3-trifluoro-4-butanolide (*III*) was prepared by a photochemically initiated reaction of 2-propanol with methyl trifluoroacrylate.

4,4-Dimethyl-3-fluoro-2-buten-4-olide (*VIII*)

4,4-Dimethyl-3,3-difluoro-4-butanolide(*VI*) (1·62 g; 10 mmol) was heated with anhydrous potassium fluoride (11·6 g; 200 mmol) to 180°C for 30 minutes. The product *VIII* was obtained as a fraction, boiling in the range 100 — 105°C/107 Torr (1·0 g; 76·8%). Gas–liquid chromatography: 15% poly(1,4-butanediol succinate), 120 cm column, 80°C; silicone elastomer E 16, 240 cm column, 100°C.

Photochemical Reduction of the Compounds *I— III*

A. *Preparative reaction*: A mixture of the substrate (*I— III*; 0·04 mol) and solvent (2 mol) was irradiated in a quartz reactor with a UV high-pressure lamp (Hg, 80 W, Tesla) for 10 hours at

18—20°C in a stream of argon. The low-boiling fractions were distilled off and the products (*IV—VI* and *VII*) were isolated by preparative gas–liquid chromatography: 45% poly(1,4-butane-diol succinate), 500 cm column, 160—200°C.

TABLE I

NMR Spectra of the Compounds *IV—VI* and *VIII*

Compound	Spectrum[a]	Character of the peaks[b]
IV	A	q 4·32 (1), $^3J_{HH} = 7-8$, O—CH; m 3·74—3·92 (2), —CH$_2$O; s 3·70 (3), COOCH$_3$; q 3·02 (2), $^3J_{HF} = 14-16$, —CF$_2$CH$_2$—; m 1·88 to 2·08 (4), —CH$_2$CH$_2$—CH—
	B[c]	(AB - spectrum); m −106 (F$_A$), m −111·8 (F$_B$), $^2J_{AB} = 257$, —CF$_2$—
V	A	s 3·64 (3), —CO$_2$CH$_3$; s 3·46 (3), CH$_3$O—CF$_2$; t 2·89 (2), $^3J_{HF} = 10·2$, —CH$_2$—;
	B	t −74·7(2), $^3J_{HF} = 9·5$, CF$_2$
VI	A	t 3·12 (2), $^3J_{HF} = 13-14$, —CH$_2$—; s 1·48 (6), (CH$_2$)$_3$;
	B[c]	s −110·9 (2), —CF$_2$—
VIII	A	d 5·44 (1), $^3J_{HF} = 2·1$, —CH$=$; s 1·56 (6), (CH$_3$)$_2$;
	B	d −104·8 (1), $^3J_{HF} = 2$, —CF$=$

[a] A ^{1}H-NMR spectrum, B ^{19}F-NMR spectrum (internal standard CFCl$_3$); [b] chemical shift δ (number of protons or fluorine atoms); s singlet, d doublet, t triplet, q quartet, m multiplet; coupling constants J in Hz; [c] noise decoupling of protons.

TABLE II

Infrared Spectra of Compounds *IV, V* and *VIII*

Compound	IR Absorption bands, cm^{-1}
IV	934 m, 1 003 m, 1 050 m, 1 082 s, 1 127 ms, 1 172 m, 1 218 m, 1 272 m, 1 345 m, 1 357 m, 1 438 ms, 1 753 s a 1 774 s(sh) (ν(C$=$O), 2 878 m, 2 953 m, 2 982 m
V	1 000 m, 1 045 s, 1095 m, 1 126 m, 1 158 m, 1 177 s, 1 196 s, 1 240 s, 1 294 s, 1 348 m, 1 365 m, 1 378 m, 1 434 m, 1 450 m, 1 757 s (ν(C$=$O)), 2 860 m, 2 960 s, 2 973 s
VIII	840 s, 880 m, 937 s, 981 m, 1 090 s, 1 177 s, 1 242 s, 1 350 s, 1 677 s, (ν(C$=$C)), 1 780 s (ν(C$=$O)), 2 940 w, 2 990 w

B. *Relative reduction rate and reducing power of solvents.* A mixture of the substrate (*I—III*; 0·01 mol), solvent (0·50 mol) and n-hexane (3 mmol, internal standard) was irradiated under the conditions described in *A*. Samples were withdrawn during the reaction and analysed by gas—liquid chromatography (15% silicone elastomer E 301, 240 cm column, 120—180°C). The decrease in the starting fluoro derivatives was calculated using a calibration graph hexane-fluoro derivative *I—III*. Mass spectrum: compound *IV* (ionic species m/e, relative intensity %): 195/0·15 $(M + 1)^+$, 193/0·1 $(M - 1)^+$, 174/39 $(M—HF)^+$, 163/69 $(M—CH_3O)^+$, 143/17 $(M—CH_4FO)^+$, 115/100 $(M—C_2H_4FO_2)^+$, 95/25, 91/24, 71/58 $(C_4H_7O)^+$; compound *V*: 111/12·7 $(M——C_2H_3O)^+$, 81/8 $(C_2H_3F_2O)^+$, 59/59 $(C_2H_3O_2)^+$, 51/14 $(CH_4FO)^+$, 45/100 $(C_2H_5O)^+$, 43/27 $(C_2H_3O)^+$.

Reaction Products

Structure of the products *IV—VIII* was determined and confirmed by ^{1}H-NMR and ^{19}F-NMR spectra (Table I), IR spectra (Table II), mass spectrometry (compounds *IV*, *V* and *VII*) and elemental analyses. Pinacolone and octahydro-2,2'-bifuran (*VII*) are described in the literature. Compounds *IV* and *V* were isolated by gas—liquid chromatography. For the compound *IV* (98% purity, $C_8H_{12}F_2O_3$ (194·1)) calculated: 49·48% C, 6·22% H, 19·56% F; found: 49·62% C, 6·41% H, 19·42% F. For the compound *V* (97% purity, $C_5H_8F_2O_3$ (154·1)) calculated: 24·65% F; found: 25·02% F. For the compound *VIII* (98% purity, $C_6H_7FO_2$ (130·1)) calculated: 14·61% F; found: 14·65% F.

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Translated by M. Tichý.