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GENERATION AND SYNTHETIC USE OF ALKYL RADICALS WITH $[CpFe(CO)_2]_2$ AS MEDIATOR

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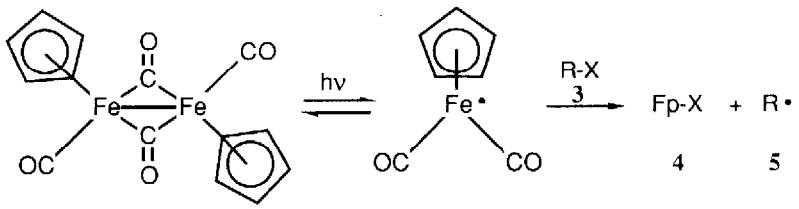
Summary: Irradiation of dimeric iron complex **1** in the presence of alkyl halides yields alkyl radicals that are useful in organic synthesis.

Radical reactions with organotin compounds as mediators have proved to be very useful in organic synthesis.[2)] The disadvantage of organotin compounds is their toxicity, so there is a need to replace tin by other elements. We have now observed that iron complex **1** can be applied to organic synthesis via alkyl radicals.



1 **2**

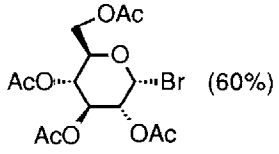
1 = $(Fp)_2$ **2** = Fp•

Under irradiation the dimeric iron complex **1** yields the monomeric iron radical **2** that abstracts halogen atoms from halides **3**.[3)] This leads to iron halide **4** and alkyl radical **5**. Acrylonitrile can trap this radical in methanol yielding **6**. In a typical procedure 1.0 mmol of cyclohexyl iodide, 1.5 mmol of iron complex **1**, and 10 mmol of acrylonitrile in 30 ml of methanol are irradiated at 15°C for 3 h with a 250 W sun lamp. Evaporation, extraction of the residue with diethyl ether, and chromatography on silica gel (pentane:ether = 20:1) gives product **6** ($R=C_6H_{11}$) in 90% yield. Following this procedure prim., sec., and tert. iodides as well as benzyl, allyl and glucosyl bromides **3** give products **6** in 60 to 90% yields.

$$\text{R-X} + \text{H}_2\text{C=CH-CN} \xrightarrow{(\text{Fp})_2 / h\nu} \text{R-CH}_2\text{-CH}_2\text{-CN}$$

3 **6**

R-X (yields of **6**):

n-$C_{10}H_{21}$-I (83%)	 (60%)	C_6H_5-CH_2-Br	(65%)
c-C_6H_{11}-I (90%)		H_2C=CH-CH_2-Br	(60%)
t-C_4H_9-I (70%)			

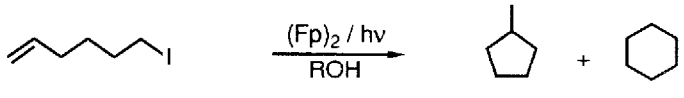
Reactions with alkenes, substituted by less electron withdrawing groups, and/or in aprotic solvents not only lead to addition products **9** but also to substitution products **10.**

$$\text{C}_6\text{H}_{11}\text{-I} + \text{H}_2\text{C=CYZ} \xrightarrow{(\text{Fp})_2 / h\nu} \text{C}_6\text{H}_{11}\text{-CH}_2\text{-CHYZ} + \text{C}_6\text{H}_{11}\text{-CH=CYZ}$$

7 **8** **9** **10**

Alkene **8**	Solvent	Products **9 : 10**	**9 + 10**
H_2C=CHCN	CH_3OH	>98 : 2	90%
	THF	66 : 34	65%
	CH_2Cl_2	55 : 45	80%
	C_6H_6	50 : 50	76%
H_2C=$CHCO_2Me$	CH_3OH	>98 : 2	55%
H_2C=C(CN)OEt	CH_3OH	88 : 12	77%
	C_6H_6	50 : 50	65%
H_2C=$C(Ph)_2$	CH_3OH	< 2 : 98	60%

Whereas in methanol acrylonitrile yields only addition product **9,** in benzene an equal amount of substitution product **10** is formed . With phenylstyrene only the substitution product **10** is produced, even in methanol. A pair of electron withdrawing and electron donating substituents at the alkene **8** leads to a mixture of **9** and **10** in methanol as well as in benzene. The occurence of free radicals as intermediates can be demonstrated by cyclization reactions. Thus, treatment of hexenyl radical **11** with the iron complex **1** under irradiation gives cyclization products **12** and **13** in a 98:2 ratio. This is typical for a radical cyclization reaction.[4)]



11 **12** **13**

98 : 2

Intermolecular trapping experiments with alkenes also demonstrate the existence of free alkyl radicals as intermediates in the CC-bond forming step. The rel. rates of addition reactions are within

experimental error independent of the precursor of the intermediates whether they are generated from cyclohexyl iodide with iron complex **1** or from cyclohexylmercuric acetate with $NaBH_4$ (Table 1). The reaction of alkylmercuric salts with $NaBH_4$ is known to give free radicals.[5)]

Table 1. Relative rates of cyclohexyl radicals generated by different methods at 20°C.

Alkene	Relative Rate	
	$C_6H_{11}I$ / **1**	$C_6H_{11}HgOAc$ / $NaBH_4$
$H_2C=C(CN)OEt$	0.38	0.48
$H_2C=C(Ph)_2$	0.58	0.51
$H_2C=CHCO_2Me$	≡ 1.0	≡ 1.0
$H_2C=CHCN$	3.0	3.6
$H_2C=C(Cl)CN$	33	31

In contrast to the radical CC-bond formation, the hydrogen abstraction step is not a radical but an anionic reaction. Thus the reaction of cyclohexyl iodide (**7**) and iron complex **1** with acrylonitrile in CH_3OD gives the monodeuterated product **14**. The same monodeuterated product **14** is formed upon irradiation of bromide **15** with the dimeric iron complex **1** in CH_3OD.

$$\underset{\mathbf{7}}{C_6H_{11}\text{-}I} + H_2C{=}CH\text{-}CN \xrightarrow[CH_3OD]{1\,/\,h\nu} \underset{90\,\%}{} C_6H_{11}\text{-}CH_2\text{-}\underset{D}{CH}\text{-}CN \xleftarrow[CH_3OD]{1\,/\,h\nu} \underset{90\,\%}{} C_6H_{11}\text{-}CH_2\text{-}\underset{Br}{CH}\text{-}CN$$

14 **15**

The mechanism of this new synthetic method is therefore similar to that using alkylcobaloxime as radical precursor[6)]. In both cases free radicals are formed that add to alkenes and give adduct radicals. The ionic hydrogen abstraction in methanol occurs presumably via a new organometal intermediate. This solvolysis competes with an elimination reaction which leads to the unsaturated product. The ratio of solvolysis versus elimination increases with increasing electron withdrawing ability of the substituents Y and Z at the alkene.

$$\begin{array}{ccccc} (Fp)_2 + R\text{-}X & \xrightarrow[H_2C=CYZ]{h\nu} & R\text{-}CH_2\text{-}CHYZ + R\text{-}CH{=}CYZ & & \\ \Big\downarrow\, h\nu & & & & \Big\uparrow \\ Fp\bullet + R\bullet & \xrightarrow[H_2C=CYZ]{} & R\text{-}CH_2\text{-}\dot{C}YZ + Fp\bullet & \rightleftharpoons & R\text{-}CH_2\text{-}CYZ\text{-}Fp \end{array}$$

(-Fp-X)

This "iron method" has the advantage that the radical is generated directly from the alkyl halide. Using the "cobalt method" [6,7] the organometallic compound has to be synthesized first from the alkyl halide before the radicals can be generated. Compared to the "vitamin B_{12} method"[8] the use of iron complex **1** permits a reaction under non-reducing conditions.

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