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COMPARISON OF GIF-TYPE REACTIVITY TOWARDS ALKANES WITH STANDARD RADICAL REACTION SELECTIVITY. GIF OXIDATION OF *n*-BUTANE AND PROPANE

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Abstract: A precise comparison has been made between radical bromination of a series of saturated hydrocarbons using $BrCCl_3$ and the bromination of the same series with the same reagent under Gif-type ($GoAgg^{III}$) conditions. The relative reactivities in the two series are completely different and confirm a difference in mechanism.

Experiments with *n*-butane and with propane have shown that these gases react with the usual Gif selectivity to furnish 2-butanone and acetone respectively.

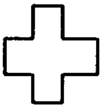
The Gif family of systems for the selective functionalization of saturated hydrocarbons has the unusual substitution pattern ($CH_2 > CH \geq CH_3$).[1] This is not compatible with normal free radical attack. Furthermore, the chemoselectivity of the Gif-type reactions is different from normal radical reactions. Saturated hydrocarbons are attacked faster than primary and secondary alcohols and ethers.[2]

There is good evidence that the reagent is an ^{V}Fe oxenoid ($^{V}Fe{=}O$) species that inserts itself into the C-H bond.[3] The selectivity seen is a compromise between bond strength and steric hindrance.

There is evidence that the first intermediate **A** in the sequence has an iron-carbon σ-bond ($^{V}Fe{-}CHR^1R^2$). **A** can be captured by four reagents (PhSeSePh, PhSSPh, $CHBr_3$, CCl_4) which react readily with carbon radicals.[4] However, two reagents, pyridine and hydrogen sulfide, which also capture carbon radicals readily, do not interfere in the standard ketonization reaction. This has been carefully studied in the case of pyridine[5]; in less detail for hydrogen sulfide.[6]

The present communication compares known radical bromination with $BrCCl_3$, for a series of saturated hydrocarbons, with the reaction of the same reagent with the same series of hydrocarbons under $GoAgg^{III}$ conditions.[8]

The radical bromination results are summarized in Table 1. From the data, the reactivity order per hydrogen was as summarized in (i) with **4** being 1.0 by definition.



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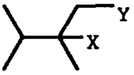
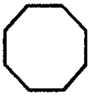


2 X=Y=H
6 X=Br, Y=H
7 X=H, Y=Br



3

4

5

Table 1[a]

R^1H	R^2H	R^1 or R^2H mmol	$BrCCl_3$ mmol	R^2Br/R^1Br (m ratio)	Rel. React. per H $R^2(H)/R^1(H)$	Temp. of Bromination (°C)
1	**2**	25	25	0.45[b]	5.41[b]	98
1	**3**	25	25	1.15	1.72	105
3	**4**	50	50	0.23	0.31	76
4	**5**	50	50	1.04	1.25	78

[a] Equimolar mixtures of R^1H and R^2H were heated under reflux with $BrCCl_3$ and *ca.* 50 mg dibenzoyl peroxide. After 2 hr. about 30% of bromides was formed. An aliquot of the reaction mixture in $CDCl_3$ was analyzed by ^1H NMR.

[b] Only *t*-bromide was formed from **2**. Authentic *t* and *prim.* bromides from **2** were synthesized by standard methods.

Since Gif-type reactions are normally run at room temperature in pyridine-acetic acid, we also compared **4** and **5** under these conditions using added $BrCCl_3$. The reaction was initiated with the BEt_3-air method.[9] Analysis by g.l.c., using cycloheptane as internal standard, gave the relative reactivity of **5**/**4** as 1.36, in good agreement with the indirect comparison.

(i) **2** (*t*.H only) (10.2) > **3** (3.3) > **1** (1.9) > **5** (1.3) > **4** (1.0)

(ii) **4** (1.0) > **3** (0.76) > **5** (0.69) > **1** (0.63) > **2** (*t*.H) (0.18) > **2** (*prim.* H) (0.06)

From the limited data in the literature[7] the order for radical bromination by $BrCCl_3$ was **3** (6.9) > **5** (1.8) > **4** (1.0). At least, the order is in qualitative agreement with our results.

Saturated hydrocarbons have not been brominated before using $BrCCl_3$ under Gif-type conditions. We used the $GoAgg^{III}$ system[10] with picolinic acid as ligand. From the results in Table 2, the reactivity order per

Table 2

R^1H	R^2H	R^1Br (%)	R^2Br (%)	(%)Mass Balance for R^1H	(%)Mass Balance for R^2H
4	5	24.4	14.1	93	--
4	**1**	19.5	24.7	88	100
4	**3**	31.3	39.6	91	92
1	**2**	23.3	**6** 0.57	99	
			7 1.15		

hydrogen is as shown in (ii). A further experiment with a direct comparison between **4** and **2** gave **6** (0.25) and **7** (0.11) in agreement with the order established indirectly.[11]

The results for radical bromination (i) are completely different from those for Gif-type bromination (ii), confirming that different activation processes are involved.

We have also compared the oxidation and phenylselenation of cyclohexane and cyclopentane. The results are summarized in Table 3. In the three Gif-type systems (Entries 1-3) cyclohexane per hydrogen is nearly twice as reactive as cyclopentane. In contrast for radical bromination cyclopentane is more reactive by a factor of 1.3 (Entry 4).

Table 3

Entry	Procedure	**4** mmol	**5** mmol	**4** Derivs. / **5** Derivs.
1	Oxidation Gif^{III} (air)	20	20	2.1
2	Bromination GoAg^{III} ($BrCCl_3$)	2.5	2.5	1.7
3	Phenylselenation Gif^{III} (air)	20	20	1.8
4	$BrCCl_3$ Radical Bromination	50	50	0.77

This communication, with its precise comparison of the reactivity of saturated hydrocarbons, reinforces again the difference between radical and Gif-type functionalization. Gif-type systems do not show radical attack on saturated hydrocarbons.

On numerous occasions we have been asked if Gif-type functionalization applies also to small molecular saturated hydrocarbons. GoAgg^{III} oxidation[8] of *n*-butane at 2 atm. at room temperature gave mainly 2-butanone with a yield of 25% with respect to the hydrogen peroxide used. Some 2-butanol was formed (ketone/alcohol ratio 11.5). Similar oxidation of propane gave acetone (13% efficiency based on hydrogen peroxide). These preliminary results are promising and show that Gif-type functionalization is not molecular weight dependent.

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8. For definition of the nomenclature used for Gif-type systems see Ref. 5. GoAgg^{II} is H_2O_2-Fe^3 in pyridine-acetic acid (or other acid). GoAgg^{III} is the same, but with an extra ligand, in this work, picolinic acid.
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