Tetrahedron Letters, Vol. 33, No. 48, pp. 7377-7380, 1992
Printed in Great Britain

0040-4039/92 $5.00 + .00
Pergamon Press Ltd

REDUCTIVE DECARBOXYLATION OF N-(ACYLOXY)PHTHALIMIDES VIA REDOX-INITIATED RADICAL CHAIN MECHANISM

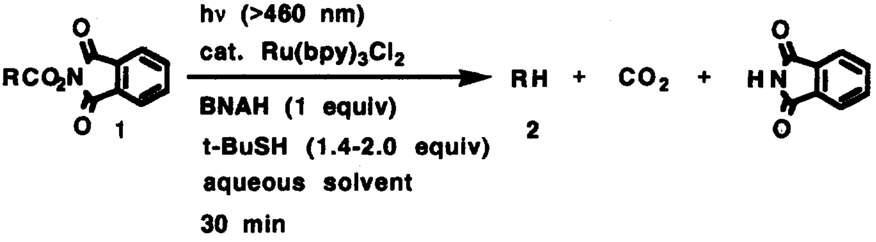
Keiji Okada,* Katsura Okubo, Naoto Morita, and Masaji Oda*
Department of Chemistry, Faculty of Science, Osaka University,
Toyonaka, Osaka 560, Japan

Abstract. Highly efficient reductive decarboxylation of N-(acyloxy)phthalimides which are readily prepared from carboxylic acids was achieved by visible light irradiation using $Ru(bpy)_3Cl_2$ as a sensitizer in the presence of BNAH and *t*-BuSH via radical chain mechanism.

Reductive decarboxylation of carboxylic acid derivatives leading to alkanes is synthetically useful reaction. Hitherto, several methods have been reported.[1,2a,3] Among them, the method developed by Barton and co-workers using radical addition to *O*-ester of thiohydroxamic acid derivatives is reported to proceed thermally and photochemically via radical chain mechanism,[1] although the quantum yield of the photochemical version has not been reported. We have reported a photosensitized decarboxylation of N-(acyloxy)phthalimides which can be easily prepared from carboxylic acids in high yields.[2] The quantum yield of 1,6-bis(dimethylamino)-pyrene-sensitized reaction was about 0.1.[2a] In order to improve the reaction efficiency, we examined several redox systems and found that the redox combination of $Ru(bpy)_3Cl_2$[4] and 1-benzyl-1,4-dihydronicotinamide (BNAH)[5] is useful for a decarboxylative Michael addition in which the quantum yield is a little over unity.[2c] At that time, we thought that the reductive decarboxylation which may be carried out in the presence of hydrogen donor such as *t*-BuSH would not proceed in high efficiency: The decarboxylated radical would mainly abstract hydrogen from *t*-BuSH and not from BNAH; therefore radical chain mechanism would not be expected. However, in contrast to our thought, the reaction efficiency considerably increased in the presence of *t*-BuSH. We now report a highly efficient reductive decarboxylation in which the quantum yield reaches 15; in relation to the mechanism, AIBN-initiated thermal decarboxylation reaction is also reported.

Irradiation of a THF-water (7:3, 40 ml)[6] solution of $Ru(bpy)_3Cl_2$ (10 mg), N-(acyloxy)phthalimide (**1a**, 200 mg), BNAH (117 mg, 1 equiv) and *t*-BuSH (0.1 ml, 1.6 equiv) with visible light (>460 nm from a 500-W Xenon lamp) for 30 min under a nitrogen atmosphere produced the decarboxylated alkane (**2a**) in 82% yield. Under the conditions, incident light is absorbed only by $Ru(bpy)_3Cl_2$. The reaction is general for various primary, secondary, and tertiary carboxylic acid derivatives (Table 1).

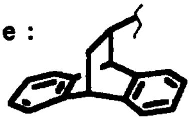
Table 1. Reductive Photodecarboxylation of N-(Acyloxy)phthalimides via Redox-Initiated Radical Chain Mechanism



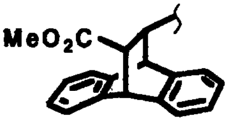
R = a : p-t-$BuC_6H_4(CH_2)_3$- b : $(PhCH_2)_2CH$- c : 1-adamantyl

d : n-$C_{15}H_{31}$-

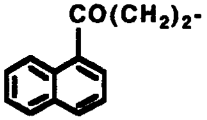
e :



f :



g :



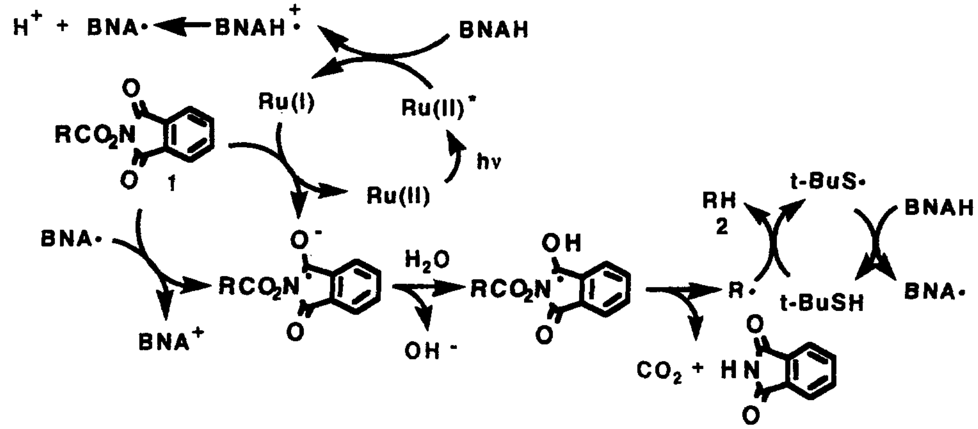
h : 9-triptycyl

compound	solvent (7:3)	*t*-BuSH (equiv)	yield of 2 (%)	quantum yield
1 a	THF-H_2O	1.6	82	2.2
1 a	CH_3CN-H_2O	1.6	74	4.6
1 a	CH_3CN-H_2O	0	37	-[a]
1 b	THF-H_2O	1.7	93	7.0
1 b	CH_3CN-H_2O	1.7	92	15.3
1 b	CH_3CN-H_2O	0	40	3.9
1 c	THF-H_2O	1.4	86	0.9
1 c	CH_3CN-H_2O	1.4	88	1.5
1 d	THF-H_2O	1.8	90	-[a]
1 e	THF-H_2O	1.8	78	-[a]
1 f	THF-H_2O	2.0	81	-[a]
1 g	THF-H_2O	1.7	71	-[a]
1 h	THF-H_2O	2.0	60	-[a]

[a] not determined

These reactions are very clean. The decarboxylated product is easily separated from the sensitizer and the produced phthalimide by extraction or by using short path chromatography. Although the reaction proceeds in the absence of *t*-BuSH, the chemical and quantum yields are considerably lowered. Table 1 also shows the quantum yields for the selected compounds under the conditions ([substrate] = 10 mM, [BNAH] = 50 mM, [Ru(bpy)3Cl2] = 4.5 mM, [*t*-BuSH] = 44 mM in a degassed sealed cell).[7] The quantum yield in aqueous acetonitrile is higher than that in aqueous THF, and in both solvents the value increases in the order of secondary > primary > tertiary carboxylic acid derivatives. The maximum value (15.3) is observed in the case of **1b** in aqueous acetonitrile. These results clearly indicate participation of radical chain processes. Scheme 1 represents a possible mechanism. The initial step of the reaction would involve the electron transfer from BNAH to the excited state of the Ru-complex to produce $Ru(bpy)_3^+$ and BNA radical,[2c,8] both of which reduce **1** to finally give the decarboxylated radical according to our previous studies.[2a,c] A key step proposed in Scheme 1 is the hydrogen abstraction of *t*-BuS radical from BNAH to reproduce BNA radical; thus the radical chain process is accomplished. The electron transfer from BNA radical to **1** is a little endothermic by 3-6 kcal/mol;[2c,9] however the process would be feasible under the conditions (at high concentration of **1** at room temperature).

Scheme 1



From Scheme 1, one may expect that if BNA radical is produced in suitably polar solvents by other procedures, the similar reaction should occur. Thus, AIBN-initiated thermal reaction of **1a**, **1b** or **1c** in acetonitrile [at refluxed temperature under a nitrogen atmosphere in the presence of AIBN (0.25 equiv), BNAH (1 equiv) and *t*-BuSH (5-10 equiv)] gave **2a** (61%), **2b** (80%), **2c** (37%), respectively. In this reaction, the produced cyanopropyl radical may abstract hydrogen from *t*-BuSH or BNAH. Both processes would finally produce BNA radical. Although the procedure of this reaction is simple, the yield is poorer than that of the photochemical reaction. This is partly due to the thermal instability of BNA radical which decomposes to nicotinamide and benzyl radical.[10]

In sum, the reductive decarboxylation of carboxylic acids is now effectively carried out through N-(acyloxy)phthalimides with the combination of BNA radical. Since the photochemical reaction proceeds with high efficiency, it is possible to employ several light sources [e.g. projector lamp, halogen lamp, or even sunlight (ca. 6 h)].

References and Notes

1 (a) D.H.R. Barton, D. Crich, and W.B. Motherwell, *J. Chem. Soc., Chem. Commun.*, **1983**, 939. (b) D.H.R. Barton, D. Crich, W.B. Motherwell, *Tetrahedron*, **1985**, *41*, 3901. (c) D.H.R. Barton, S.Z. Zard, *Pure Appl. Chem.*, **1986**, *58*, 675. (d) W.G. Dauben, D.P. Bridon, B.A. Kowalczyk, *J. Org. Chem.*, **1990**, *55*, 376. The related radical chain process was also reported; (e) P. Delduc, C. Tailhan, S.Z. Zard, *J. Chem. Soc., Chem. Commun.*, **1988**, 308. (f) J.E. Forbes, S.Z. Zard, *J. Am. Chem. Soc.*, **1990**, *112*, 2034.

2 (a) K. Okada, K. Okamoto, M. Oda, *J. Am. Chem. Soc.*, **1988**, *110*, 8736. (b) K. Okada, K. Okamoto, M. Oda, *J. Chem. Soc., Chem. Commun.*, **1989**, 1636. (c) K. Okada, K. Okamoto, N. Morita, K. Okubo, M. Oda, *J. Am. Chem. Soc.*, **1991**, *113*, 9401.

3 M. Hasebe and T. Tsuchiya, *Tetrahedron Lett.*, **1987**, *28*, 6207.

4 I. Fujita, H. Kobayashi, *Ber. Bunsenges. Phys. Chem.*, **1972**, *76*, 115.

5 D. Mauzerall, F.H. Westheimer, *J. Am. Chem. Soc.*, **1955**, *77*, 2261.

6 In comparison with the Barton method (ref. 1), the present reaction has an advantage of the feasibility in aqueous solvents. Water content in this mixed solvent is not important; 30%-water system was chosen simply because of its high water content and its reasonable solubility to **1**.

7 Quantum yields were determined by using a Schlenk tube in which solid **BNAH** and an aqueous THF or acetonitrile solution of **1**, *t*-BuSH, and $Ru(bpy)_3Cl_2$ were separately degassed and mixed into a UV-cell attached to the Schlenk tube. Light intensity (2.14×10^{-7} einstein/min at 545 nm) were determined by using Reinecke's salt actinometer; E.E. Wegner, A.W. Adamson, *J. Am. Chem. Soc.*, **1966**, *88*, 394.

8 (a) C. Pac, M. Ihama, M. Yasuda, Y. Miyauchi, H. Sakurai, *J. Am. Chem. Soc.*, **1981**, *103*, 6495. (b) C. Pac, Y. Miyauchi, O. Ishitani, M. Ihama, M. Yasuda, H. Sakurai, *J. Org. Chem.*, **1984**, *49*, 26. (c) O. Ishitani, M. Ihama, Y. Miyauchi, C. Pac, *J. Chem. Soc., Perkin Trans. 1*, **1985**, 1527. (d) O. Ishitani, S. Yanagida, S. Takamuku, C. Pac., *J. Org. Chem.*, **1987**, *52*, 2790. (e) S. Fukuzumi, T. Tanaka, In *Photoinduced Electron Transfer*; M. Chanon, M.A. Fox, Eds.; Elsevier: New York, 1988: Part C, pp 578-635 and references cited therein.

9 S. Fukuzumi, S. Koumitsu, K. Hironaka, T. Tanaka, *J. Am. Chem. Soc.*, **1987**, *109*, 305.

10 Benzyl radical can be trapped by diphenyl diselenide under the similar conditions without *t*-BuSH.

(Received in Japan 27 July 1992)