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Photochemical Deuteration of *ortho*-Substituted *N*-(Diphenylmethylene)acetamides[1)]

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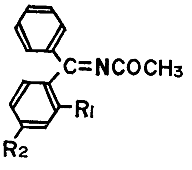
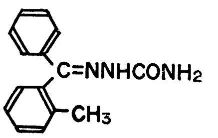
The alkyl hydrogens of *N*-(2-alkyldiphenylmethylene)acetamides were found to be readily replaced with deuterium on irradiation in deuteriomethanol (CH_3OD). It is proposed that the deuteration proceeds *via* an enamide isomer produced by intramolecular hydrogen transfer from the *o*-alkyl group to the excited C=N double bond. An intermolecular hydrogen atom abstraction pathway was excluded because neither *N*-(4-methyldiphenylmethylene)acetamide in deuteriomethanol(CH_3OD) nor diphenylmethane in deuteriomethanol(CH_3OD) in the presence of *N*-(diphenylmethylene)acetamide was deuterated. Intramolecular hydrogen abstraction is essential for the deuteration, because no deuteration occurs on irradiation of 2-methylbenzophenone semicarbazone which undergoes no photoreduction. The difference in reactivities of the *ortho*-substituted imines between in solution and in a rigid matrix is discussed from the viewpoint of *syn-anti* isomerization.

In previous papers we have reported that the imine **1** which has a C=N double bond conjugated with a carbonyl group undergoes photochemical reduction in hydrogen-donating solvents such as alcohol or ether,[2)] and reduction and reductive addition in alkyl benzenes or aliphatic olefins.[3)] In spite of the recent accumulation of reports of the photoreduction of simple imines,[2—5)] its reduction pathway has not yet been unambiguously characterized. Fischer[4)] and Padwa and others[6,7)] have proposed that the reactive intermediates in these reactions are exclusively the excited states of the carbonyl compounds contained as impurities in the reaction mixtures. The lack of reactivity of the excited states of imines was explained by a feasible deactivation *via* *syn-anti* isomerization.[7)] Nevertheless, it is still open to question whether this interpretation is applicable to different kinds of imine, *e.g.*, **1**.





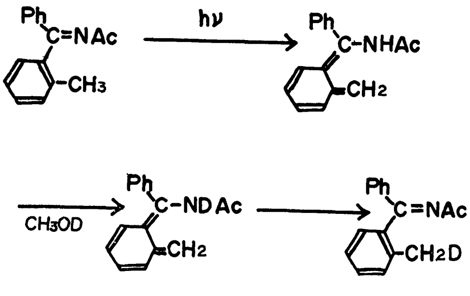
1; R_1=H, R_2=H **4**
2a; $R_1=CH_3$, R_2=H
2b; $R_1=CH_2C_6H_5$, R_2=H
3; R_1=H, $R_2=CH_3$

We expected that participation of an impurity in the hydrogen abstraction reaction could be prevented by setting the hydrogen-accepting imino group and the hydrogen-donating alkyl group in one molecule. *N*-(2-Methyldiphenylmethylene)acetamide (**2a**), *N*-(2-benzyldiphenylmethylene)acetamide (**2b**), and *N*-(4-methyldiphenylmethylene)acetamide (**3**) were prepared and the photogenerated intermediates were detected by the exchange of hydrogen in the alkyl group with deuterium in deuteriomethanol (CH_3OD). Changes in the absorption spectra during irradiation and the photochemical behavior of 2-alkylbenzophenone semicarbazone (**4**) were investigated as well.

Results and Discussion

Deuteration. The 2- (**2a**) and 4-methyl (**3**) substituted *N*-(diphenylmethylene)acetamides were prepared and photochemically deuterated at the 2- and 4-methyl positions. A solution of each compound in a deuteriomethanol(CH_3OD)–benzene mixed solvent was irradiated with light of wavelength longer than 320 nm at room temperature for 8 hr. After irradiation, the solvent was removed and the NMR spectrum of the recovered imine was measured. The spectrum of the recovered **2a** revealed that 0.30±0.09 atoms of deuterium per molecule were incorporated in the 2-methyl group of **2a**, while no deuteration was observed in **3**. This striking contrast is apparently due to the difference between the geometrical positions of the hydrogen-donating methyl groups. In other words, this is an example of the *ortho*-effect. It is also noteworthy that the acetyl hydrogens in **2a** or **3** remained undeuterated throughout the above irradiations.

Mechanism of Deuteration. The lack of deuteration of **3** indicates that some intramolecular interaction between the *N*-acetylimino group and the 2-methyl group of **2a**, possibly intramolecular hydrogen atom abstraction *via* a six-membered cyclic transition state formation, is involved in the photodeuteration of **2a**.



The following experiment showed that the deuteration of **2a** does not proceed *via* an intermolecular hydrogen atom abstraction. Thus diphenylmethane and imine **1** were used as a hydrogen donor and an acceptor, respectively, for a typical intermolecular reaction. When a solution of diphenylmethane and **1** in deuteriomethamol(CH_3OD)–benzene was irradiated at room temperature, even after irradiation for 86 hr NMR and mass spectra showed no evidence of deuteration. This shows that the deuteration of **2a** must proceed *via* an intramolecular hydrogen abstraction pathway.

Furthermore, the participation of the hydrogen abstraction in the deuteration was confirmed by studying the photochemical behavior of 2-methylbenzophenone semicarbazone (**4**). Generally, it is known that irradiation of *N*-acylimines in hydrogen donors results in reduction of the C=N double bond, but no photoreductions of semicarbazones have been reported yet. In fact, semicarbazone **4** gave no photoreduction product. As might have been expected from the inability of semicarbazones to abstract a hydrogen atom photochemically, no deuteration of **4** was observed after irradiation for 20 hr in deuteriomethanol(CH_3OD). This result indicates that the deuteration of **2a** results from hydrogen abstraction in its excited state.

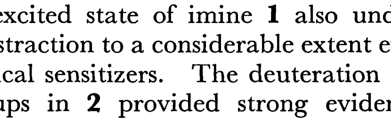
Attempts of Spectrophotometrical Detection of Intermediate. 2-Methylbenzophenone (**5a**) isoelectronic with the imine **2a**, is known to undergo photochemical deuteration, which has been interpreted as the consequence of the hydrogen-deuterium exchange between deuteriomethanol(CH_3OD) and the enol isomer of **5a** generated by the intramolecular hydrogen atom transfer.[8,9] This photoenol was detected spectrophotometrically as a colored species which was stable only at low temperature. It was, therefore, expected that upon irradiation at 77 K the imine **2a** would also produce the corresponding enamide which might be detected as a colored species in a rigid matrix. Since it was not possible to eliminate the impurity **5a** completely from the liquid **2a**, the crystalline 2-benzyl derivative **2b** was used for measuring the absorption spectra of the reaction system. The imine **2b** was carefully recrystallized several times from dry cyclohexane. 2-Benzylbenzophenone (**5b**), as well as **5a**, has also been reported to generate a colored species at low temperature and to undergo deuteration upon irradiation.[9]

A solution of **2b** in an alcoholic solvent was irradiated and the change in the absorption spectrum of the reaction mixture was followed. At room temperature no color change was observed. At 77 K in the matrix, the colored enol of the impurity **5b** was often observed (λ_{max} 430—480 nm) when insufficiently purified **2b** was used. However more careful purification removed the coloration completely. When a small amount of water was added to the purified sample which was subsequently allowed to stand at room temperature for 48 hr, coloration due to **5b** produced by the hydrolysis of **2b** was again observed at 77 K. Furthermore, a solution of unpurified **2a** in an alcoholic solvent gave a colored species (λ_{max} 405 nm and 430 nm) on irradiation at 77 K, but the coloration was removed by addition of phenylhydrazine to the system. Phenylhydrazine would react with the impurity **5a** to give a less reactive species, phenylhydrazone. As described above, it was concluded that the observed colorations were due to the photoenols of impurities.[10] An attempt to detect the intermediate enamide spectroscopically was unfortunately unsuccessful. This observation, however, is not in conflict with the contention that the enamides are involved in deuteration, as discussed in the next section.

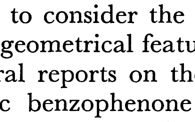
In order to examine the influence of impurities, the deuteration of the impurity-free **2b** was rigorously checked. A solution of impurity-free **2b** in a deuteriomethanol(CH_3OD)–toluene solvent was first irradiated at 77 K to check the absence of the coloration due to the impurity. Then the irradiation was continued at room temperature for 20 hr. The amount of deuterium contained in the recovered **2b** was found by NMR spectroscopy to be 0.3 atom per molecule in good agreement with the figure determined by mass spectroscopy. The deuterium atom was found to be located at the benzylic position. It was, therefore, concluded that the deuteration of the *ortho*-substituted imines **2** proceeded indeed *via* the excited states of **2** and that the impurity, a ketone, did not participate in the deuteration *via* a chemical sensitization mechanism.

Intramolecular Hydrogen Atom Abstraction and Molecular Geometry of 2. Padwa and Dharan[6] claimed that irradiation of simple imines resulted in isomerization about the C=N double bond which dissipated the excitation energy and resulted in inhibition of hydrogen abstraction by the excited imine. The results of the present study, however, showed that hydrogen abstraction is indeed able to proceed when the hydrogen-donating alkyl group is located at a geometrically and consequently kinetically preferable position within the molecule. Moreover it has been found in our laboratory and will be reported in a separate paper[11] that the excited state of imine **1** also underwent hydrogen abstraction to a considerable extent even without any chemical sensitizers. The deuteration of the *ortho*-alkyl groups in **2** provided strong evidence for the participation of the excited states of these imines (**1** and **2**) in the hydrogen abstraction.

It was necessary to consider the molecular geometry of **2** to discuss the geometrical features of the hydrogen abstraction. Several reports on the *syn-anti* isomerization of asymmetric benzophenone imines in solution showed that the *para*-substituted derivatives[12] mostly undergo rapid isomerization at room temperature whereas the *ortho*-substituted ones[13] exist exclusively in the *syn*(*Z*)-form. This would be the case in *ortho*-substituted **2a** and **2b**, shifting the equilibrium to the *syn(Z)*-form. The fact that the intermediate enamide was not detected even at low temperature can be reasonably explained as follows. Because the lone pair of the nitrogen atom in *syn(Z)*-**2** is in position opposite to the *ortho*-alkyl group and also the isomerization of *syn(Z)*-**2** to the *anti(E)*-isomer is prevented at



syn(*Z*)-**2** *anti*(*E*)-**2**



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77 K in a rigid matrix, the excitation energy is dissipated by radiative or radiationless processes without hydrogen abstraction.[14] In fact, no deuteration could be detected on irradiation of **2a** at 77 K, which is consistent with the absence of coloration of the pure imine.[15] On the contrary, irradiation of **2** at room temperature in solution results in the formation of the *anti(E)*-isomer by rotation about the C=N double bond.[16] The excited state of the *anti(E)*-isomer is supposed to be the active species in the hydrogen abstraction and the photochemical deuteration. In fact, Ogata[17] and Stermitz[18] reported that azomethine **6** undergoes photochemical intramolecular hydrogen abstraction.

Experimental

General. Ultraviolet spectra were recorded on a Shimadzu MPS-50L spectrophotometer. Infrared spectra were taken as liquid film or in Nujol mulls on a Jasco IR-E spectrophotometer. Nuclear magnetic resonance spectra were taken on a Japan Electron Optics Laboratory Model PS-100 spectrometer using tetramethylsilane as the internal standard. The mass spectra were recorded on a Hitachi RMS-4 mass spectrometer, in which the ionization energy was 80 eV. The samples were injected directly at 120 °C or injected through a Hitachi 063 gas chromatograph (SE30, 3 mm$\phi \times$ 2 m, 225 °C). Melting points were determined with a Yanagimoto micro melting point apparatus. All irradiations were carried out in a quartz reactor equipped with a Ushio type 501C 500W ultrahigh pressure mercury lamp through a glass filter transparent to wavelengths longer than 320 nm.

Materials. Monodeuteriomethanol(CH_3OD) was obtained from Merck. Benzene, toluene, and cyclohexane were dried over metallic sodium, methanol over magnesium, and 2-propanol over barium oxide, and distilled. Diphenylmethane was recrystallized from petroleum ether.

N-*(Diphenylmethylene)acetamide* (***1***) was prepared in the usual way.[19] *N*-Acetylation was carried out with acetic anhydride.

N-*(2- or 4-Methyldiphenylmethylene)acetamide* (***2a*** *or* ***3***) was prepared by the coupling of benzonitrile with the Grignard reagent of the corresponding bromotoluene,[19] followed by *N*-acetylation with acetic anhydride. **2a**: bp, 152 °C (1 mmHg); IR (liquid film): 1690(C=O), 1640(C=N) cm^{-1}; NMR(CCl_4): δ 1.9(acetyl CH_3), 2.2(CH_3), 7.1—7.8 (9H, aromatic ring protons). **3**: IR(liquid film): 1690(C=O), 1640(C=N) cm^{-1}; NMR(CCl_4): δ 1.9 (acetyl CH_3), 2.3(CH_3), 7.0—7.6(9H, aromatic).

N-*(2-Benzyldiphenylmethylene)acetamide(**2b**).* The Grignard coupling of bromobenzene and 2-chlorobenzyl chloride gave 2-chlorodiphenylmethane.[20] 2-Chlorodiphenylmethane was refluxed in pyridine in the presence of cuprous cyanide to give 2-benzylbenzonitrile.[21] A solution of 20 g of 2-benzylbenzonitrile in 50 ml of dry diethyl ether was added to the Grignard reagent prepared from 15.7 g of bromobenzene and 2.5 g of magnesium in 100 ml of diethyl ether. The reaction mixture was refluxed for 6 hr, cooled, decomposed with 100 ml of methanol, and filtered. The solvent was evaporated and the residue was distilled under reduced pressure to give 2-benzyldiphenylmethyleneimine; 22% yield; bp, 200 °C(1 mmHg); IR(liquid film): 3240(NH), 1605(C=N) cm^{-1}; NMR(CCl_4): δ 3.8(CH_2), 6.9—7.7(14H, aromatic), 8.6(NH); Anal.: Found: C, 86.65; H, 6.00; N, 4.94%. Calcd for $C_{20}H_{17}N$: C, 88.52; H, 6.32; N, 5.16%.[22] This imine was easily acetylated with acetic anhydride to give *N*-(2-benzyldiphenylmethylene)acetamide. Careful recrystallization from cyclohexane was repeated several times until impurity-free white crystals were obtained: bp, 205 °C (1 mmHg); mp, 100—101 °C; Mass: m/e=313; IR(Nujol mull): 1690(C=O), 1640(C=N) cm^{-1}; $\lambda_{\max}^{\text{MeOH}}$ (log $\varepsilon_{\max}$):

Table 1. Results of the photodeuteration in deuteriomethanol(CH_3OD)

Compound	Irr. time (hr)	Analysis		
		Method	Observed value (Calcd value)	Deuterium content (%)
1 200 mg + **Dm** 200 mg[b]	20	NMR	$\frac{\text{methylene}}{\text{phenyl}} = 0.20 \pm 0.01$	0
1 350 mg + **Dm** 200 mg[b]	86	mass	$\frac{M+1}{M} = 0.14 \pm 0.02$ (0.15)[c]	0
2a 230 mg	8	NMR	$\frac{\text{2-methyl}}{\text{acetyl}} = 0.90 \pm 0.03$	10±3
2a 230 mg (at 77 K)[d]	8	mass	$\frac{M+1}{M} = 0.19 \pm 0.02$ (0.19)[c]	0
2b 150 mg[e]	20	NMR	$\frac{\text{2-methylene}}{\text{acetyl}} = 0.59 \pm 0.03$	12±4
		mass	$\frac{M+1}{M} = 0.51 \pm 0.02$ (0.25)[c]	15±2
		mass	$\frac{M+2}{M} = 0.13 \pm 0.02$ (0.03)[c]	14±2
3 500 mg	8	NMR	$\frac{\text{4-methyl}}{\text{acetyl}} = 1.00 \pm 0.03$	0
4 100 mg	20	mass	$\frac{M+1}{M} = 0.20 \pm 0.02$ (0.18)[c]	0

a) The NMR spectra were taken in CCl_4 at room temperature. b) Recovered diphenylmethane (**Dm**) was analyzed in this run. c) The figure in the parentheses is the ratio calculated from the natural isotope abundance. d) Toluene was used in this run instead of benzene as a solvent. e) The corresponding ketone was completely eliminated from the starting material and dry toluene was used instead of benzene in this case.

215(4.54), 234(4.40), 253(4.40), 372(sh)(0.97), 382(0.66), 392(0.66)nm; NMR(CCl_4): δ 1.8(acetyl CH_3), 3.8(CH_2), 6.9—7.6(14H, aromatic). Anal.: Found: C, 84.48; H, 6.09; N, 4.44%. Calcd for $C_{22}H_{19}NO$: C, 84.31; H, 6.11; N, 4.47%.

2-Methylbenzophenone Semicarbazone(**4**) To a solution of 1 g of semicarbazide hydrochloride and 1.5 g of sodium acetate in 10 ml of water was added 10 ml of ethanol containing 1 g of 2-methylbenzophenone. Ethanol was added until the mixture became transparent. The solution was heated for half an hour and allowed to stand at room temperature over a period of several days. A new crystalline compound **4** was separated from the reaction mixture and recrystallized from ethanol: mp, 156—157 °C; Mass: $m/e=253$; IR(Nujol mull): 3300(NH), 1680(C=O)cm^{-1}; NMR (CCl_4): δ 2.2(CH_3), 6.0(NH, NH_2), 7.5(9H, aromatic). Anal.: Found: C, 71.19; H, 5.92%. Calcd for $C_{15}H_{15}N_3O$: C, 71.11; H, 5.98%.

Deuterium Exchange. Usually 2 ml of a deuteriomethanol (CH_3OD)-benzene solvent containing 100—500 mg of an imine was degassed and pure nitrogen was introduced until the system reached atmospheric pressure for experimental convenience. After being irradiated at room temperature in a quartz tube, the starting material was recovered and analyzed by NMR and mass spectroscopy. The results are summarized in Table 1.

Irradiation at Low Temperature. Unless otherwise mentioned, an oxygen-free 10^{-1} mol/l solution of the substrate in 4 ml of a methanol-2-propanol (1 : 1) solvent was irradiated at 77 K in a quartz cell with light of wavelengths longer than 320 nm. Changes in the absorption spectra were measured at 77 K in a quartz Dewar filled with liquid nitrogen.

References and Notes

1) N. Toshima, M. Saeki, and H. Hirai, *Chem. Commun.*, **1971**, 1424.

2) T. Okada, M. Kawanisi, H. Nozaki, N. Toshima, and H. Hirai, *Tetrahedron Lett.*, **1969**, 927.

3) S. Asao, N. Toshima, and H. Hirai, unpublished results. N. Toshima, S. Asao, K. Takada, and H. Hirai, *Tetrahedron Lett.* **1970**, 5123.,

4) M. Fischer, *ibid.*, **1966**, 5273; *Chem. Ber.*, **100**, 3599 (1967).

5) H. Göth, P. Cerutti, and H. Schmid, *Helv. Chem. Acta*, **48**, 1395 (1965). E. S. Huyser, R. H. S. Wang, and W. T. Short, *J. Org. Chem.*, **33**, 4323 (1968). R. O. Kan and R. L. Furey, *J. Amer. Chem. Soc.*, **90**, 1666 (1968). A. Padwa, W. Bergmark, and D. Pashayan, *ibid.*, **90**, 4458 (1968); **91**, 2653 (1969). G. Balogh and F. C. De Shryver, *Tetrahedron Lett.*, **1969**, 1371. N. Toshima, H. Hirai, and S. Makishima, *Kogyo Kagaku Zasshi*, **72**, 184 (1969). B. Fraser-Reid, A. McLean, and E. W. Usherwood, *Can. J. Chem.*, **47**, 4511 (1969). P. Beak and C. R. Payet, *J. Org. Chem.*, **35**, 3281 (1970). T. Okada, K. Saeki, M. Kawanisi, and H. Nozaki, *Tetrahedron*, **26**, 3661 (1970).

6) A. Padwa and M. Dharan, *Tetrahedron Lett.*, **1972**, 1053.

7) A. Padwa and F. Albrecht, *J. Amer. Chem. Soc.*, **94**, 1000 (1972).

8) N. C. Yang and C. Rivas, *ibid*, **83**, 2213 (1961).

9) E. F. Zwicker, L. I. Grossweiner, and N. C Yang, *ibid*, **85**, 2671 (1963). E. F. Ullman and K. R. Huffman, *Tetrahedron Lett.*, **1965**, 1863. G. Porter and M. F. Tchir, *Chem. Commun.*, **1970**, 1372. K. R. Huffman, M. Loy, and E. F. Ullman, *J. Amer. Chem. Soc.*, **87**, 5417 (1965).

10) In the preliminary communication,[1] these colored species were incorrectly attributed to the enamide isomers of the corresponding imines.

11) S. Asao, N. Toshima, and H. Hirai, in preparation.

12) D. Y. Curtin and J. W. Hausser, *J. Amer. Chem. Soc.*, **83**, 3474 (1961). D. Y. Curtin, E. J. Grubbs, and C. G. McCarty, *ibid*, **88**, 2773 (1966). M. Tabata, K. Yokota, Y. Takada, and A. Suzuki, *Chem. Lett.*, **1972**, 659. H. A. Stabb, F. Vögtle, and A. Mannschreck, *Tetrahedron Lett.*, **1965**, 697.

13) R. Van der Linde, J. W. Dornseiffen, J. U. Veenland, and Th. J. de Boer, *Spectrochim. Acta*, **25A**, 375 (1969).

14) N. J. Turro and D. S. Weiss, *J. Amer. Chem. Soc.*, **90**, 2187 (1968).

15) We acknowledge the suggestion of a referee to carry out this experiment.

16) The preceding discussion was developed on the assumption that the n-orbital on the nitrogen atom is operative in the hydrogen abstraction. The participation of the n-orbital on the oxygen atom could not be eliminated by the present study. In this case, hydrogen abstraction must proceed *via* an eight-membered cyclic transition state and the lack of coloration in the matrix must be interpreted as due to the loss of flexibility of the C=N-C=O chromophore to form an eight-membered cyclic transition state.

17) Y. Ogata and K. Takagi, *Tetrahedron*, **27**, 2785 (1971).

18) F. R. Stermitz, C. C. Wei, and C. M. O'Donnel, *J. Amer. Chem. Soc.*, **92**, 2745 (1970).

19) P. L. Pickard and T. L. Tolbert, "Organic Synthesis," Coll. Vol. V, p. 520 (1973).

20) F. A. Vingiello, S. Que, and J. Sheridan, *J. Org. Chem.*, **26**, 3202 (1961).

21) C. K. Bradsher, *J. Amer. Chem. Soc.*, **62**, 486 (1940).

22) Since this imine is easily hydrolyzed, it contains 2-methylbenzophenone inevitably. This causes the discrepancy of the elemental analysis.