Mechanism of the Oxidation Reaction with Nickel Peroxide

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Some aspects of mechanisms of the oxidation reactions using nickel peroxide which is a useful oxidant prepared from nickel sulfate with sodium hypochlorite were examined. The radical species were observed by esr in some oxidation reactions with nickel peroxide. From stoichiometric study using benzhydrol and diphenylacetonitrile, it can be concluded that one equivalent atom of available oxygen in nickel peroxide corresponds to two radical species. Using hexaphenylethane as a reactant the presence of the source of OH radical in nickel peroxide was confirmed. Accordingly, the nature of nickel peroxide can be expressed stoichiometrically by the scheme $2OH\cdot \rightarrow H_2O + O$. The oxidation reaction mechanism of benzhydrol was studied in detail in views of isotope effect and the reactions using ^{18}O-labeled compounds to support the mechanism (eq 5).

Since Nakagawa, Konaka, and Nakata[1] previously found that nickel peroxide was a useful oxidizing agent on the oxidation of alcohols, a lot of the reactions using nickel peroxide have been reported. That is, on the oxidation of amines,[2] phenols,[3] hydrazones,[4] sulfur compounds,[5] nitriles,[6] and phenothiazines,[7] on the oxidative cleavage of α-glycols[8] and *o*-phenylenediamines,[9] on the telomerization,[10] on the polymerization,[11] and on the others,[12] nickel peroxide showed the extremely attractive reactivities.

All above reactions may possibly be explained in terms of the radical reaction mechanisms. However, though the telomerization and the polymerization with nickel peroxide demonstrate the typical radical reaction the evidence of radical character in the oxidation reaction is ambiguous. Nickel peroxide obtained from nickel sulfate with sodium hypochlorite in an alkaline solution is amorphous black powder, insoluble in organic solvents and water other than acidic solvents, and is similar to manganese dioxide in its appearance and some chemical properties. Nickel peroxide has $0.30–0.35 \times 10^{-2}$ g-atom of available oxygen per gram determined by iodometry, and generally is used in a little excess of stoichiometric amount in most oxidation reactions, but the source of available oxygen is still indistinct. In the present paper, it is clarified that the oxidation reaction with nickel peroxide proceeds through the radical reaction path by esr studies and by product studies on the reaction with a stable radical. Besides, from the stoichiometrical study the source of available oxygen can be expressed in the simple scheme. Furthermore, the mechanism of the oxidation of alcohol is discussed in detail by means of isotope methods.

Electron Spin Resonance Studies.—Esr studies on the oxidation of 2,6-di-*t*-butyl-4-methylphenol (**1**) in benzene showed the presence of 2,6-di-*t*-butyl-4-methylphenoxy radical (**2**),[13] $a^{H}_{p} = 11.15\ G$ and $a^{H}_{m} = 1.69\ G$, whose decay in the flow system followed in the first order. In the case of 2,6-di-*t*-butylphenol (**4**) the spectrum of 2,6-di-*t*-butylphenoxy radical (**5**),[14] $a^{H}_{p} = 9.58\ G$ and $a^{H}_{m} = 1.93\ G$, was detected only in the flow system. The esr spectrum of 10-phenothiazinyl radical (**8**) was observed upon the oxidation of phenothiazine (**7**) with nickel peroxide in benzene in the static system. Its hyperfine splitting constants, $a^{N} = 7.04\ G$, $a^{H}_{3,7} = 3.67\ G$, $a^{H}_{1,9} = 2.85\ G$, and $a^{H}_{2,8} = a^{H}_{4,6} = 0.95\ G$, were identical with those in the reference.[15] On the esr measurement, at 2.4 min after mixing of **7** and nickel peroxide, 72.2% radical was observed and the concentration of the radical was decayed in the second order ($k = 1.2 \times 10^{-2}$ l./mol sec). On the oxidation of benzophenone oxime with nickel peroxide in benzene, esr spectrum showed the corresponding iminoxy radical,[16] $a^{N} = 31.55\ G$ and $a^{H} = 1.41\ G$ (2 H).

Aurich and Baer[17] observed the esr spectra of acyl phenyl nitroxides on the oxidation of N-acyl-N-phenylhydroxylamines with nickel peroxide[18] in benzene. This suggests the oxidation with nickel peroxide may proceed *via* the radical course. On the oxidations of **1** and **4** with nickel peroxide, 3,3′,5,5′-tetra-*t*-butylstylbene-4,4′-quinone (**3**)[3e] and 3,3′,5,5′-tetra-*t*-butyl-4,4′-diphenoquinone (**6**)[3c] are produced in 30% yield and quantitatively, respectively. While in these reactions, the observation of corresponding phenoxy radicals by esr spectroscopy may imply that these reactions proceed in the following schemes, in which eq 1 is the same mechanism as that of Bennet.[19] Since the oxidation products of phenothiazine (**7**) with

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[1] K. Nakagawa, R. Konaka, and T. Nakata, *J. Org. Chem.*, **27**, 1597 (1962).

[2] (a) K. Nakagawa and T. Tsuji, *Chem. Pharm. Bull. Jap.*, **11**, 296 (1963); (b) J. Sugita, *Nippon Kagaku Zasshi*, **88**, 659 (1967); (c) J. Sugita, *ibid.*, **88**, 1235 (1967).

[3] (a) K. Nakagawa, H. Onoue, and J. Sugita, *Chem. Pharm. Bull. Jap.*, **12**, 1135 (1964); (b) J. Sugita, *Nippon Kagaku Zasshi*, **87**, 603 (1966); (c) J. Sugita, *ibid.*, **87**, 607 (1966); (d) J. Sugita, *ibid.*, **87**, 741 (1966); (e) J. Sugita, *ibid.*, **87**, 1082 (1966); (f) H.-D. Becker, *J. Org. Chem.*, **32**, 2115 (1967); (g) M. F. Ansell and A. F. Gosden, *Chem. Commun.*, 520 (1965).

[4] (a) K. Nakagawa, H. Onoue, and K. Minami, *ibid.*, 730 (1966); (b) R. Kalish and W. H. Pirkle, *J. Amer. Chem. Soc.*, **89**, 2781 (1967).

[5] J. Sugita, *Nippon Kagaku Zasshi*, **88**, 1237 (1967).

[6] J. Sugita, *ibid.*, **88**, 668 (1967).

[7] J. Sugita and Y. Tsujino, *ibid.*, **89**, 309 (1968).

[8] K. Nakagawa, K. Igano, and J. Sugita, *Chem. Pharm. Bull. Jap.*, **12**, 403 (1964).

[9] K. Nakagawa and H. Onoue, *Tetrahedron Lett.*, 1433 (1965).

[10] (a) T. Nakata, *Kogyo Kagaku Zasshi*, **65**, 1044 (1962); (b) J. Tanaka, T. Katagiri, and T. Hirabayashi, *Nippon Kagaku Zasshi*, **88**, 1106 (1967).

[11] (a) T. Nakata, T. Otsu, and M. Imoto, *J. Polym. Sci., Part A*, **3**, 3383 (1965); (b) T. Nakata, Y. Kinoshita, T. Otsu, and M. Imoto, *Kogyo Kagaku Zasshi*, **68**, 864 (1965); (c) T. Nakata, T. Otsu, and M. Imoto, *J. Macromol. Chem.*, **1**, 553 (1966); (d) T. Nakata, T. Otsu, and M. Imoto, *ibid.*, **1**, 563 (1966); (e) T. Nakata, T. Otsu, M. Yamaguchi, and M. Imoto, *ibid.*, **A1**, 1447 (1967); (f) T. Otsu, M. Yamaguchi, T. Nakata, K. Murata, and M. Imoto, *ibid.*, **A1**, 1457 (1967).

[12] (a) K. Nakagawa, H. Onoue, and K. Minami, *Chem. Commun.*, 17 (1966); (b) C. D. Campbell and C. W. Rees, *Proc. Chem. Soc.*, 296 (1964); (c) A. Ujhidy, B. Babos, L. Markó, and A. Müller, *Ber.*, **98**, 2197 (1965).

[13] J. K. Becconsall, S. Clough, and G. Scott, *Trans. Faraday Soc.*, **56**, 459 (1960).

[14] W. G. B. Huysmans and W. A. Waters, *J. Chem. Soc., B*, 1047 (1966).

[15] C. Jackson and N. K. D. Patel, *Tetrahedron Lett.*, 2255 (1967).

[16] (a) J. R. Thomas, *J. Amer. Chem. Soc.*, **86**, 1446 (1964); (b) B. C. Gilbert and R. O. C. Norman, *J. Chem. Soc., B*, 86 (1966).

[17] H. G. Aurich and F. Baer, *Tetrahedron Lett.*, 3879 (1965).

[18] Nickel peroxide used here may have been prepared by the method of Nakagawa, *et al.*,[1] though there is no description in the reference.

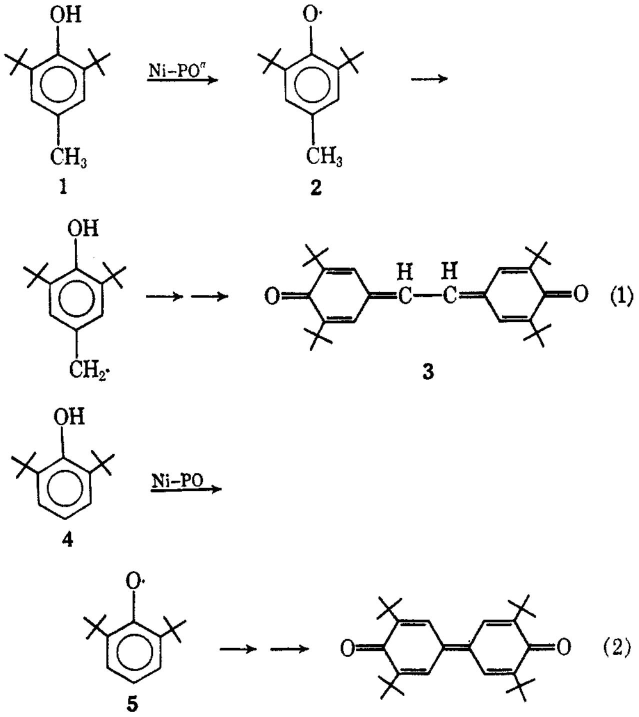
[19] J. E. Bennet, *Nature*, **186**, 385 (1960).

TABLE I

OXIDATION OF BENZHYDROL AND DIPHENYLACETONITRILE WITH NICKEL PEROXIDE[a]

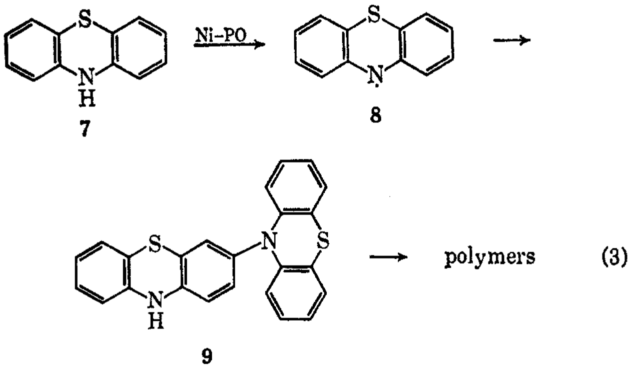
Substrate	Amt, mmol	Ni-PO mg-O*[b]	Reaction time, hr	Product	Yield, %
Benzhydrol	3	3.6	4	Benzophenone	94.5
	3	1.5	8		46.5
Diphenylacetonitrile	39	40	1	*syn*-Dicyanotetraphenylethane	98.8[c]
	20	10	1		96.9

[a] Solvent, benzene; temp, 25°. [b] Means milligram atomic equivalent of available oxygen. [c] Unpublished work by Dr. Sugita.



[a] Ni-PO nickel peroxide

nickel peroxide are 3,10′-biphenothiazinyl (9) and polymers,[7] the reaction course may be considered as in reaction 3. Benzophenone is obtained by the oxidation of benzophenone oxime with nickel peroxide.[20] Presumably, observed iminoxy radical might relate to the formation of benzophenone. As mentioned above, observed radicals by esr spectroscopy can be considered as reaction intermediates in respective oxidation reactions, and it is confirmed that nickel peroxide is capable of abstracting hydrogens of some substrates.



Stoichiometry on the Oxidation with Nickel Peroxide. —In practice, an amount of nickel peroxide needed on the oxidation is determined based on an amount of the available oxygen. For example, an amount of nickel peroxide corresponding to one atomic equivalent of available oxygen converts 1 mol of alcohol into a carbonyl compound. The results indicated in Table I clarify the stoichiometry on the oxidation with nickel peroxide. It is reasonable to explain that the formation of *syn*-dicyanotetraphenylethane is attributed to the dimerization of cyanodiphenylmethyl radical produced by hydrogen abstraction from diphenylacetonitrile with nickel peroxide. The data conclude that one atomic equivalent of available oxygen of nickel peroxide corresponds to two radical species.

Oxidation of Active Methylene and Methine Groups. —On the oxidation of toluene derivatives and diphenylmethane with nickel peroxide, benzoic acid derivatives and benzophenone were produced respectively.[21] In addition, 9,10-dihydroanthracene was oxidized for 3 hr in benzene at room temperature to give anthracene as a major product and anthraquinone as a minor one. Furthermore, on the oxidation of triphenylmethane with nickel peroxide in benzene at 55°, after 10 hr triphenylcarbinol was afforded in 2% yield and the residue was the unchanged starting material. Triphenylmethane seems to be oxidized slowly owing to steric effect.

On the other hand, the composition of nickel peroxide prepared from nickel sulfate was determined as $NiO_{2.77}H_{2.85}$ by means of elementary analysis, chelate titration, and gas chromatography. Consequently, introduction of oxygen atom into the products described above may intimate the participation of a species like OH radical in nickel peroxide.[22] It cannot be inferred, however, whether this species is contained in nickel peroxide originally,[23] or produced by the hydrogen abstraction from the substrate with active oxygen atom in nickel peroxide.[24,25]

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(20) Unpublished work by Dr. K. Nakagawa.

(21) Unpublished work by Dr. Sugita.

(22) The molecular formula of nickel peroxide may be written as $Ni_x(OH)_yO_z \cdot nH_2O$ formally.

(23) In this case the following reaction sequence may be written.

$$\geqslant CH + Ni_x(OH)_yO_z \cdot nH_2O \longrightarrow \geqslant C\cdot + Ni(OH)_{y-1}O_z \cdot (n+1)H_2O$$

$$\geqslant C\cdot + Ni_x(OH)_yO_z \cdot nH_2O \longrightarrow \geqslant COH + Ni(OH)_{y-1}O_z \cdot nH_2O$$

(24) In this case the following reaction sequence may be similarly written'

$$\geqslant CH + Ni_x(OH)_yO_z \cdot nH_2O \longrightarrow \geqslant C\cdot + Ni(OH)_{y+1}O_{z-1} \cdot nH_2O$$

$$\geqslant C\cdot + Ni_x(OH)_{y+1}O_{z-1} \cdot nH_2O \longrightarrow \geqslant COH + Ni(OH)_yO_{z-1} \cdot nH_2O$$

(25) Another path might be explained as the following chain mechanism.

$$\geqslant CH + Ni_x(OH)_yO_z \cdot nH_2O \longrightarrow \geqslant C\cdot + Ni_x(OH)_{y-1}O_z \cdot (n+1)H_2O$$

$$\geqslant C\cdot + Ni_x(OH)_yO_z \cdot nH_2O \longrightarrow \geqslant CO\cdot + Ni_x(OH)_yO_{z-1} \cdot nH_2O$$

$$\geqslant CO\cdot + \geqslant CH \longrightarrow \geqslant COH + \geqslant C\cdot$$

Reaction of Nickel Peroxide with Free Radicals.—Phenylazotriphenylmethane was decomposed in benzene at 65° in the presence of 1.1 equivalent amounts of nickel peroxide to yield triphenylcarbinol (56.3%), triphenylmethane (47.7%), and biphenyl (79.2%).[26,27] On the decomposition of phenylazotriphenylmethane itself in benzene, triphenylcarbinol was not produced. Since it is well known that triphenylmethyl radical is produced on the decomposition of phenylazotriphenylmethane, these facts may imply that the formation of triphenylcarbinol may be attributed to the reaction of triphenylmethyl radical with nickel peroxide though the source of OH group is uncertain.

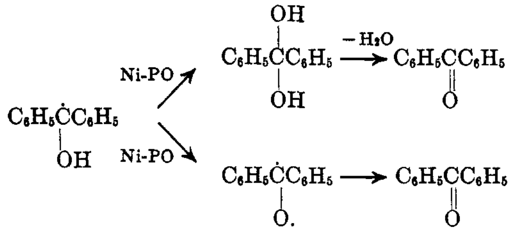
A mixture of hexaphenylethane[28] and 0.6 equivalent amount of nickel peroxide for triphenylmethyl radical dissociated from hexaphenylethane was stirred in benzene for 2 hr at room temperature to give triphenylcarbinol in 90% yield. In benzene-d_6 solution, triphenylcarbinol which did not show the absorption of OD in the ir spectrum was afforded quantitatively by using 1.2 equivalent amounts of nickel peroxide. In both cases, no biphenyl was produced. These results indicate that the source of OH group is in nickel peroxide itself, not produced by the hydrogen abstraction from a reaction system. Furthermore, since 1 mol of triphenylcarbinol was produced from 1 mol of triphenylmethyl radical and about one-half equivalent amount of nickel peroxide, it is reasonable to conclude that one atomic equivalent of available oxygen determined by iodometry in nickel peroxide corresponds to two OH radical species. Consequently, the nature of nickel peroxide may be explained schematically as

$$\text{nickel peroxide} \longrightarrow 2\text{OH}\cdot \longrightarrow \text{O}^* + \text{H}_2\text{O}$$

and in terms of having two characteristic abilities of hydrogen abstraction and OH radical donation. Thus the production of triphenylcarbinol from triphenylmethane or phenylazotriphenylmethane and the formation of other oxygen containing compounds from hydrocarbons can be elucidated by the above characters.

The Oxidation Mechanism of Alcohols with Nickel Peroxide.—The isotope effect for the oxidation of $(C_6H_5)_2CDOH$ was examined to verify the first step of the oxidation of alcohols with nickel peroxide. The reaction rates of the oxidation of $(C_6H_5)_2CHOH$ and $(C_6H_5)_2CDOH$ with excess nickel peroxide at 1° were followed by glpc to give $k_H = 1.693 \times 10^{-4}$ sec^{-1} and $k_D = 2.287 \times 10^{-5}$ sec^{-1}; accordingly $k_H/k_D = 7.4$. This fact shows that the oxidation of benzhydrol with nickel peroxide begins from the hydrogen abstraction on α position of the alcohol. The alternative explanation, the hydrogen abstraction from OH bond, was eliminated.[29,30]

Two mechanisms, eq 4 and 5,[31,32] for the formation of benzophenone after the hydrogen abstraction from the α position appear reasonable. The distinction of the two paths was accomplished by means of benzhydrol labeled with oxygen-18.



$$C_6H_5\dot{C}(OH)C_6H_5 \xrightarrow{\text{Ni-PO}} C_6H_5C(OH)_2C_6H_5 \xrightarrow{-H_2O} C_6H_5C(=O)C_6H_5 \quad (4)$$

$$C_6H_5\dot{C}(OH)C_6H_5 \xrightarrow{\text{Ni-PO}} C_6H_5C(O\cdot)C_6H_5 \longrightarrow C_6H_5C(=O)C_6H_5 \quad (5)$$

First in order to check the exchange reaction of oxygen between the product and nickel peroxide, benzophenone-^{18}O and nickel peroxide (1.2 equivalent amounts) were mixed under stirring in benzene at room temperature and the ^{18}O content of isolated benzophenone was analyzed. It was somewhat surprising to find that the considerable fast exchange reaction occurred and the rate of decrease was about 5.7% of excess ^{18}O per hour. Furthermore, the deactivated nickel peroxide and alumina for column chromatography also exchanged oxygen of benzophenone but it was observed that the procedures of glpc of benzophenone and benzhydrol and of mixing of benzophenone and benzhydrol in benzene without nickel peroxide did not cause the exchange reaction. Hence, the oxidation of benzhydrol-^{18}O with nickel peroxide (0.5 equivalent amount) was carried out in a short reaction time (1 hr) at room temperature and the reaction products were separated by means of the preparative glpc and the ^{18}O content was analyzed. According to the above procedure benzophenone of ^{18}O 1.137% content and benzhydrol of ^{18}O 1.204% content were afforded in 22.8 and 77.2% yield, respectively, from benzhydrol of ^{18}O 1.297% content. Subsequently, the oxidation reaction mechanism of benzhydrol with nickel peroxide may be elucidated by the reaction path (5) on the surface of nickel peroxide.

Experimental Section

Materials.—Nickel peroxide was prepared by the method of Nakagawa, *et al.*,[1] and its available oxygen content was 0.318×10^{-2} g-atom per gram. 2,6-Di-*t*-butyl-4-methylphenol and 2,6-di-*t*-butylphenol were Tokyo Kasei E.P. grade and were used without further purification. Phenothiazine, benzhydrol, diphenylacetonitrile, and triphenylmethane were purified by recrystallization from commercial reagents. Benzophenone oxime was prepared from hydroxylamine hydrochloride and benzophenone by the ordinary method. Phenylazotriphenylmethane was prepared by the oxidation of N-phenyl-N-tritylhydrazine prepared from trityl chloride and phenylhydrazine

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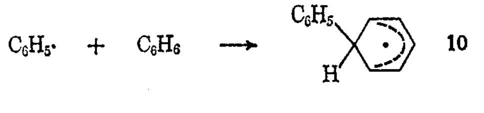
[26] Triphenylmethane and biphenyl were possibly produced by the following reactions.[27]

$$(C_6H_5)_3CN{=\!=}NC_6H_5 \xrightarrow{65°} (C_6H_5)_3C\cdot + C_6H_5\cdot + N_2$$



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$$10 + (C_6H_5)_3C\cdot \longrightarrow (C_6H_5)_3CH + (C_6H_5)_2$$

$$10 + C_6H_5\cdot \longrightarrow (C_6H_5)_2 + C_6H_6$$

[27] (a) E. L. Eliel, M. Eberhardt, O. Simamura, and S. Meyerson, *Tetrahedron Lett.*, 749 (1962); (b) G. A. Russell and R. F. Bridger, *ibid.*, 737 (1963).

[28] M. Gomberg and C. S. Schoeple, *J. Amer. Chem. Soc.*, **39**, 1658 (1924).

[29] Generally, the free-radical reaction mechanism of the oxidation of alcohols is explicable in terms of hydrogen abstraction from α position of alcohols;[30] in the case of the oxidation with nickel peroxide, however, it is probable that the OH group is attacked owing to the decrease of the bond dissociation energy of the O–H bond caused by the adsorption of alcohols on the surface of nickel peroxide.

[30] R. S. Davidson, *Quart. Rev.* (London), **14**, 249 (1967).

[31] Pryor[32] calculated the dissociation energy of $C_6H_5\dot{C}(OH)C_6H_5 \rightarrow C_6H_5C(\dot{O})C_6H_5 + H\cdot$ to be 102 kcal/mol.

[32] W. A. Pryor, "Free Radicals," McGraw-Hill Book Co., Inc., New York, N. Y., 1966, p 75.

according to the method of Cohen, *et al.*[33] All above compounds have the correct melting points.

Electron Spin Resonance Technique.—The esr spectra were recorded with a Varian V-4502 spectrometer having a 12-in. magnet with 100-kHz field modulation. Cells similar to the type proposed by Russell, *et al.*,[34] were used for the static method and esr spectra were measured immediately after mixing the solutions of a substrate and nickel peroxide degassed by introducing prepurified nitrogen. The flow method was carried out according to the method of Huysmans, *et al.*[14] Determinations of the radical concentrations were made compared with a standard solution of diphenylpicrylhydrazyl by using a Varian V-4532 dual-sample cavity.

General Oxidation Procedure.—A mixture of a substrate and a calculated amount of nickel peroxide required stoichiometrically based on the available oxygen was stirred in benzene or ether vigorously by means of a magnetic stirrer at a proper constant temperature. The reaction mixture was filtered to remove the solid of nickel compound. The filtrate was treated in the usual methods of recrystallization, column chromatography, and/or glpc to determine the structures of products and yields.

Composition of Nickel Peroxide.—The composition of nickel peroxide prepared by Nakagawa's method was determined as follows: Ni, chelate titration using EDTA and Cu-PAN indicator,[35] 52.31%; Na, magnesium-uranyl-acetate method,[36] 0.75%; Cl, volumetry using $AgNO_3$, 0.16%; H_2O, gravimetry on decomposition at 900°, 23.01%; O_2, glpc on decomposition at 900°, 5.35%; ash, residue on decomposition at 900°, 67.45%. Assuming that the deficient amount to 100% was volatile impurities, calculating from above data, the molecular formula was $NiO_{2.77}H_{2.85}$.

Reaction of Hexaphenylethane with Nickel Peroxide.—Hexaphenylethane was prepared from triphenylmethyl chloride, mercury, and lead powder in benzene under vacuum at room temperature for 68 hr according to Gomberg's method,[28] and recrystallized from acetone under vacuum, mp 140–145° (lit.[28] mp 145–147°).

A mixture of 162 mg of hexaphenylethane, 251 mg of nickel peroxide (1.2 equivalent amounts), and 5 ml of benzene-d_6 was stirred at room temperature under argon atmosphere. After 2 hr, the nickel compound was filtered off and the filtrate was evaporated. On recrystallization of the residue from *n*-hexane, 169 mg (98%) of pure triphenylcarbinol was obtained. In view of infrared spectrum of this compound, the presence of D was not recognized. Using 0.6 equivalent amount of nickel peroxide in benzene under the condition, 90% yield of triphenylcarbinol was obtained. In both cases, no triphenylmethyl peroxide was observed. While hexaphenylethane did not change in the absence of oxygen in a benzene–water mixture, on exposure to air of this mixture, a 94% yield of triphenylmethyl peroxide was obtained.

Isotope Effect of Oxidation of Benzhydrol with Nickel Peroxide.—In a mixture of 0.5 mmol of benzhydrol and 5 equivalent amount of nickel peroxide 17 ml of ether was added at 1° under vigorous stirring; after the appropriate time the mixture was quenched by 15% HCl aqueous solution, extracted with ether, and dried over calcium chloride, and an amount of benzhydrol was determined by glpc (column, diethylene glycol succinate polyester, 5%, 2.25 m; column temperature, 200°; internal standard, azobenzene). α-Deuteriobenzhydrol prepared by reduction of benzophenone with lithium aluminum deuteride was treated with the same procedure. The reaction rates of both oxidations are shown in Table II. Both reaction rates were expressed by the first-order reaction rate equation and the rate constants were $k_H = 1.693 \times 10^{-4}\ \text{sec}^{-1}$ and $k_D = 2.287 \times 10^{-5}\ \text{sec}^{-1}$.

TABLE II

THE OXIDATION REACTION RATES OF BENZHYDROL AND α-DEUTERIOBENZHYDROL AT 1°

	Reaction time, min				
	10	20	40	60	80
$(C_6H_5)_2CHOH$ (%)	82.3	75.6	60.7	54.8	
$(C_6H_5)_2CDOH$ (%)	92.2	92.0	87.7	86.1	86.8

Preparation of Benzhydrol-^{18}O and Benzophenone-^{18}O.—Benzhydryl bromide (8.1 g) was dissolved in 100 ml of a mixture of water-free THF and $H_2{}^{18}O$ (YEDA Research and Development Co., Ltd., ^{18}O 1.71%), and allowed to stand overnight at room temperature. The reaction mixture was evaporated under vacuum to remove THF and extracted with water-free benzene. After evaporation of benzene and twice recrystallization from *n*-hexane 4 g of benzhydrol was obtained, mp 66°. Tlc showed one spot, and the infrared spectrum showed the same as that of authentic benzhydrol. *Anal.* Calcd for $C_{13}H_{12}O$: C, 84.75; H, 6.57; O, 8.68. Found: C, 84.92; H, 6.63; O, 8.69. Analysis of ^{18}O content was accomplished by the method of Denney, *et al.*,[37] applying Schütze–Unterzaucher's method.[38] The isotope ratio was determined by Hitachi RMU-6E mass spectrometer with Faraday cup collector. The content of ^{18}O of benzhydrol prepared above was 1.297%. Benzophenone-^{18}O was prepared according to Doering, *et al.*,[39] as follows. A mixture of 10 g of commercial dichlorodiphenylmethane and 5 g of $H_2{}^{18}O$ (^{18}O content 1.71%) was stirred at 90° for 6 hr. The resulting product was evaporated and recrystallized twice from *n*-hexane, giving benzophenone-^{18}O containing 1.49% ^{18}O.

Oxidation of Benzhydrol-^{18}O with Nickel Peroxide.—In order to check the exchange reaction of benzophenone-^{18}O produced during the oxidation of benzhydrol-^{18}O, 100 mg of benzophenone-^{8}O (^{18}O content, 1.49%) was treated with 210 mg of nickel peroxide under the reaction condition to show the decrease of the ^{18}O content as follows: 0 hr, 100%; 0.5 hr, 97.5%; 1 hr, 95.7%; 2 hr, 81.9%; 3 hr, 83.9%; 5 hr, 72.2%; 29 hr, 21.2%. Furthermore, to examine the oxygen exchange reaction of benzophenone-^{18}O in column chromatography for the separation procedure of the reaction mixture, benzophenone-^{18}O was mixed with alumina to result the rapid decrease of the ^{18}O content. However, on mixing benzophenone-^{18}O with benzhydrol in benzene without nickel peroxide and on separation of benzhydrol-^{18}O and benzophenone-^{18}O by glpc (5% diethylene glycol succinate polyester column) oxygen exchange reactions of benzophenone-^{18}O and benzhydrol-^{18}O did not occur within experimental error.

A mixture of 200 mg of benzhydrol-^{18}O (^{18}O content, 1.297%), 200 mg of nickel peroxide (0.5 equivalent amount), and 5 ml of benzene was stirred at room temperature for 1 hr. The reaction mixture was filtered off to remove the nickel compound and evaporated. The yield of benzophenone was 22.8% by glpc analysis and 29.6 mg of benzophenone and 68.34 mg of benzhydrol were obtained by means of preparative glpc. The contents of ^{18}O in the resulting benzophenone and benzhydrol were 1.137 and 1.204%, respectively.

Registry No.—Benzhydrol-^{18}O, 19639-48-6; benzhydrol, 91-01-0; diphenylacetonitrile, 86-29-3; hexaphenylethane, 17854-07-8.

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(33) S. G. Cohen and C. H. Wang, *J. Amer. Chem. Soc.*, **75**, 5504 (1953).

(34) G. A. Russell, E. G. Janzen, and E. T. Strom, *ibid.*, **86**, 1807 (1964).

(35) H. Flaschka and H. Abdine, *Chem.-Analyst*, **45**, 58 (1956).

(36) E. R. Caley, *J. Amer. Chem. Soc.*, **51**, 1965 (1929).

(37) D. B. Denney and M. A. Greenbaum, *ibid.*, **79**, 979 (1957).

(38) This method was checked by the direct measurement based on a parent peak in mass spectrometry and the oxidation method using $HgCl_2$ [D. Rittenberg and L. Ponticorvo, *Int. J. Appl. Radiat. Isotopes*, **1**, 208 (1956); S. Oae, T. Kitao, and Y. Kitaoka, *Ann. Rept. Radiat. Center Osaka Pref.*, **1**, 31 (1961)] to give the same result.

(39) W. von E. Doering and E. Dorfman, *J. Amer. Chem. Soc.*, **75**, 5595 (1953).