# Tetrabutylammonium Periodate; A Selective and Versatile Oxidant for Organic Substrates

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Some attention has, in recent years, been paid to the use of quaternary ammonium salts for a wide range of reactions[1] in homogeneous phase in non-aqueous solvents. The solubility of quaternary ammonium salts in several solvents provides advantages in terms of high reaction rates, low reaction temperatures, and absence of side reactions. Some of the hitherto available crystalline quaternary ammonium salts of reducing[2] and oxidizing[3] anions have already been studied with respect to their use in organic synthesis. We report here that the water-insoluble tetrabutylammonium periodate[4], $(n\text{-}C_4H_9)_4NJO_4$, can be easily prepared from sodium periodate and tetrabutylammonium hydrogen sulfate in aqueous solution. Yields are excellent since the compound is recovered from water by filtration as a white material which can be stored in the dark for long periods without decrease in oxidising power.

Besides the cleavage of 1,2-diols by periodates, an interesting application of aqueous sodium metaperiodate is the selective oxidation of sulfides to sulfoxides[5] at room temperature (aryl sulfides) or ice-bath temperature (dialkyl sulfides) using a slight excess of oxidizing agent. At higher temperatures or with more than 1 equiv of oxidant, overoxidation may occur. It has recently been reported[6] that this oxidation can also be carried out with sodium metaperiodate adsorbed on acidic alumina and an excess of oxidant in protic solvents. We have investigated the same reaction using tetrabutylammonium periodate in boiling chloroform and have found that dialkyl, alkyl aryl, and diaryl sulfides **1** may thus be selectively oxidized to the sulfoxides **2** in good yields.

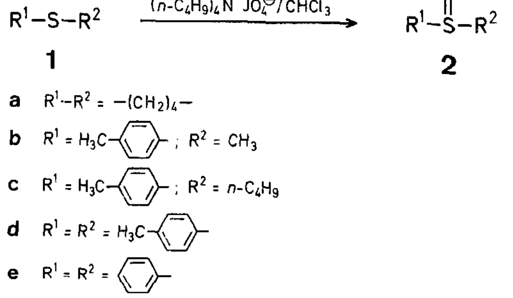

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**Table.** Sulfoxides (**2**), Aldehydes (**4**), and Benzoic Acids (**6**) prepared

| Product[a] | Reaction time [h] | Yield[b] [%] | m.p. or b.p./torr [°C] found | reported | I.R. (neat) $\nu_{C=O}$, $\nu_{S=O}$ [cm$^{-1}$] |
|---|---|---|---|---|---|
| **2a**[c] | 2 | 90 | b.p. 40–42°/2.5 | b.p. 45°/3[8] | 1045 |
| **2b** | 4 | 86 | m.p. 74° | m.p. 73–74.5°[9] | 1050 |
| **2c** | 4 | 85 | m.p. 88–89° | m.p. 89.5–90°[9] | 1050 |
| **2d** | 7 | 70 | m.p. 95° | m.p. 94–94.5°[10] | 1050 |
| **2e**[c] | 8 | 72 | b.p. 206°/13 | b.p. 215°/15[10] | 1030 |
| **4a** | 5 | 86 | b.p. 180°/760 | b.p. 180°/760[10] | 1705 |
| **4b**[c] | 3 | 90 | b.p. 161°/13 | b.p. 185°/25[10] | 1715 |
| **4c** | 3 | 90 | b.p. 101°/760 | b.p. 103°/760[10] | 1715 |
| **4d** | 4 | 85 | b.p. 76°/760 | b.p. 75.7°/760[10] | 1715 |
| **6a** | 15[d] | 78 | m.p. 254° | m.p. 254.5°[10] | 1740[e] |
| **6b** | 24[d] | 75 | b.p. 247–249°/760 | b.p. 249°/760[10] | 1740[e] |

[a] The microanalyses were in good agreement with the calculated values: C, ±0.20; H, ±0.20.

[b] Yield of isolated product.

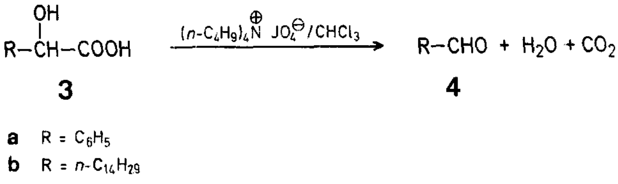
[c] Purified by bulb-to-bulb distillation in a glass-tube oven Büchi GKR 500.

[d] In boiling dioxan.

[e] As nujol mull.

The sulfoxides are easily purified (removal of the polar tetrabutylammonium salts) by filtration through a silica-gel column. In the case of diaryl sulfoxides, the yields decrease with prolonged reaction times.

Whereas the oxidative cleavage of 1,2-diols with periodates is a useful and well documented method, the oxidative decarboxylation of $\alpha$-hydroxycarboxylic acids with periodates appears to be a slow and rather difficult reaction. The only examples reported are decarboxylations of $\alpha$-hydroxycarboxylic acids of the bile acid series using sodium periodate in water/acetic acid/acetone[7]. We have found that $\alpha$-hydroxycarboxylic acids **3** are conveniently decarboxylated to the corresponding nor-aldehydes **4** by reaction with tetrabutylammonium periodate in boiling chloroform.

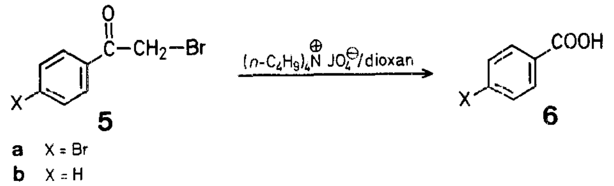


$$\underset{\mathbf{3}}{\text{R-}\overset{\text{OH}}{\overset{|}{\text{C}}}\text{H-COOH}} \xrightarrow{(n\text{-}C_4H_9)_4\overset{\oplus}{N}\ JO_4^{\ominus}/CHCl_3} \underset{\mathbf{4}}{\text{R-CHO}} + H_2O + CO_2$$

**a** R = $C_6H_5$
**b** R = $n$-$C_{14}H_{29}$
**c** R = $n$-$C_4H_9$
**d** R = $n$-$C_3H_7$

This reaction seems to be selective for $\alpha$-hydroxycarboxylic acids; we found that 2-oxoglutaric acid does not react with tetrabutylammonium periodate. The fact that a stoichiometric amount of iodine is set free in the reaction of $\alpha$-hydroxycarboxylic acids **3** with the reagent suggests the use of tetrabutylammonium periodate in analytical chemistry.

As a further type of reaction we found that $\omega$-bromoacetophenone (**5b**) and 4,$\omega$-dibromoacetophenone (**5a**) are oxidatively cleaved to benzoic acid (**6b**) and 4-bromobenzoic acid (**6a**), respectively, in good yields upon treatment with tetrabutylammonium periodate in boiling dioxan for 24 or 15 h.



**a** X = Br
**b** X = H

Under the same conditions, chloroacetone was found to be unaffected after 48 h.

The oxidative cleavage of compounds **5** might be rationalized by the assumption of iodate ester formation via substitution of the Br-atom at the activated methylene group by periodate ion and subsequent cleavage steps similar to the mechanism of the cleavage of $\alpha$-hydroxyketones by periodates[5].

**Tetrabutylammonium Periodate:**

A solution of sodium periodate ($NaJO_4$; 21.4 g, 0.1 mol) in water (150 ml) is added with stirring to a solution of tetrabutylammonium hydrogen sulfate (34.0 g, 0.1 mol) in water (50 ml). The precipitated tetrabutylammonium periodate is isolated by suction and dried over phosphorus pentoxide; yield: 42 g (~100%). Recrystallization from diisopropyl ether affords the analytically pure product; m.p. 158–159 °C.

| | | | | |
|---|---|---|---|---|
| $C_{16}H_{36}NJO_4$ | calc. | C 44.34 | H 8.31 | N 3.23 |
| (433.4) | found | 44.78 | 8.64 | 3.32 |

Since the dried or recrystallized tetrabutylammonium periodate becomes yellow in the light, the salt has to be stored in the dark. No loss of oxidizing power is observed after long storage.

**Tetrahydrothiophene *S*-Oxide (2a); Typical Procedure:**

Tetrahydrothiophene (**1a**; 2.64 g, 0.03 mol) is added to a solution of tetrabutylammonium periodate (13.75 g, 0.03 mol) in chloroform (50 ml). The mixture is refluxed and the progress of the reaction monitored by G. L. C. analysis (1% SE 30 on Chromosorb Q, 100–120 mesh). Upon completion of the reaction, the mixture is allowed to cool and then filtered through a column containing silica gel (100 g). The resultant product is distilled in vacuo to afford pure **2a**; yield: 2.8 g (90%); b.p. 40–42 °C/2.5 torr.

**Pentanal (4c) from 2-Hydroxyhexanoic Acid (3c); Typical Procedure:**

2-Hydroxyhexanoic acid (**3c**; 1.32 g, 0.01 mol) is added to a solution of tetrabutylammonium periodate (4.25 g, 0.01 mol) in chloroform (10 ml). The mixture is refluxed and the progress of the reaction monitored by G. L. C. analysis (1% SE 30). The mixture becomes purple within 1 h. Upon completion of the reaction, the mixture is washed with 10% sodium thiosulfate solution (50 ml). The organic phase is dried with sodium sulfate and fractionally distilled; yield: 0.77 g (90%); b.p. 101 °C/760 torr.

**Benzoic Acid (6b) from ω-Bromoacetophenone (5b); Typical Procedure:**

A solution of ω-bromoacetophenone (**5b**; 1.99 g, 0.01 mol) in dioxan (5 ml) is added to a solution of tetrabutylammonium periodate (4.25 g, 0.01 mol) in dioxan (10 ml). The mixture is refluxed for ~24 h [Completion of the reaction may be determined by T. L. C. and G. L. C. analysis of aliquots of the mixture upon conversion of **6b** to its methyl ester]. A saturated solution (50 ml) of sodium hydrogen carbonate is added and the mixture extracted with ethyl acetate (3 × 15 ml). The aqueous phase is acidified and then extracted with ether (320, ml), the ether evaporated, and the residual product recrystallized from ethanol yield: 0.93 g (75%); m. p. 247–249 °C.

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