33. Synthesis of Concentrated ^{18}O-Labelled Hydrogen Peroxide and of ^{2}H-, ^{13}C- and ^{18}O-Labelled Peroxyformic Acid

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(29.XI.82)

Summary

A method is described for the preparation of concentrated solutions (50–70%) of ^{18}O-labelled H_2O_2 in water. All singly ^{2}H-, ^{13}C- and ^{18}O-labelled species of peroxyformic acid have been synthesized by the reaction of appropriately labelled formic acid and H_2O_2.

Introduction. – The complete set of all singly substituted isotopic species of peroxyformic acid[2]) was needed for the determination of the molecular structure of this compound by the microwave spectroscopic method [1]. To date the geometrical structures of free peroxycarboxylic acids in the gaseous state are not known from experimental investigations. From two X-ray studies [2] [3] it appears that, in the crystalline state, two peroxycarboxylic acid molecules are held together by H-bonds. An earlier microwave investigation of peroxyacetic acid revealed that the conformation in the gaseous state is strongly influenced by an intramolecular H-bond [4].

This observation is in accord with recent *ab initio* calculations [5] and the fact that peroxycarboxylic acids do not dimerize in the gaseous state unlike carboxylic acids [6]. With the exception of a deuteriated species [4], we know of no reports of the preparation of isotopically substituted species of peroxycarboxylic acids. We report here the synthesis of ^{2}H-, ^{13}C- and ^{18}O-labelled species of peroxyformic acid. The synthesis can easily be adapted to the homologous peroxycarboxylic acids. For the synthesis of peroxy-group-labelled species, concentrated solutions of ^{18}O-labelled H_2O_2 were required. Several methods for the preparation of small amounts of ^{18}O-labelled H_2O_2 have been described in the literature [7–9]. All procedures led to very dilute solutions of H_2O_2 in water. Our first attempts to concentrate dilute solutions by evaporation of water *in vacuo* failed due to the easy decomposition of concentrated solutions by catalytic processes. Eventually we discovered a method of concentrating H_2O_2-solutions involving the careful elimination of all contaminants which could induce or catalyse decomposition. By this method solutions of concentration up to 70% were obtained.

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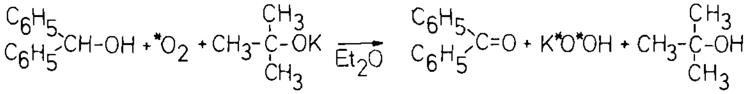
[2]) Other names in the literature: performic acid, methaneperoxic acid, peroxymethanoic acid.

Methods. – a) *[^{18}O]hydrogen peroxide.* The preparation of concentrated solutions of ^{18}O-labelled H_2O_2 started from the base-catalyzed autoxidation of benzhydrol with labelled molecular oxygen following the procedures of *Sawaki & Foote* [10] and *Le Berre* [11]. In the first step potassium hydroperoxide is formed according to *Reaction 1.*



$$(C_6H_5)_2CH\text{-}OH + {}^{*}O_2 + CH_3\text{-}\underset{CH_3}{\overset{CH_3}{C}}\text{-}OK \xrightarrow[Et_2O]{} (C_6H_5)_2C{=}O + K{}^{*}O{}^{*}OH + CH_3\text{-}\underset{CH_3}{\overset{CH_3}{C}}\text{-}OH \qquad (1)$$

Potassium hydroperoxide precipitates from the ether solution and is collected by filtration. H_2O_2 is liberated from the K-salt by addition of dilute HCl according to *Reaction 2.*

$$K{}^{*}O{}^{*}OH + HCl \longrightarrow H_2{}^{*}O_2 + KCl \qquad (2)$$

Since potassium hydroperoxide is rather unstable and decomposes rapidly to form potassium superoxide it is necessary to perform the reactions in a cooled vessel and to isolate it immediately with cooled laboratory equipment (0°). The dilute aqueous solution obtained from *Reaction 2* is purified to remove organic material and concentrated by slow evaporation of water *in vacuo* [15]. Addition of a stabilizer helps to prevent decomposition [13]. A special distillation apparatus was designed for small amounts of aqueous solutions (see the *Fig.*). It should be noted that H_2O_2 and potassium hydroperoxide can cause severe burns to skin, eyes and mucous membranes. Concentrated solutions may react explosively with or cause combustion of organic materials. Necessary precautions are imperative.

b) *Peroxyformic acid.* Peroxyformic acid was prepared according to *Reaction 3*

$$HCOOH + H_2O_2 \rightleftharpoons HCOOOH + H_2O \qquad (3)$$

in the presence of a dehydrating agent such as concentrated sulfuric acid [17] or metaboric acid [18]. Concentrated H_2O_2-solutions (>50%) and formic acid (>95%) were required. Best yields were obtained with H_2O_2-concentrations above 95%. The product was allowed to evaporate into a 5-liter glass bulb after one hour of reaction. The different isotopic species were synthesized from appropriately labelled formic acid or H_2O_2. A summary of all isotopic species prepared is given in the *Table*. Due to the high explosion risk of peroxycarboxylic acids [19] only small amounts (≤ 3 mmol) were prepared at a time. All operations were carried

Table. *Synthesis of isotopic species of peroxyformic acid*

Products		Synthesized from
$HCOO{}^{2}H$		$HCOOH$ and ${}^{2}H_2O_2$
${}^{2}HCOOOH$		${}^{2}HCOO{}^{2}H$ and H_2O_2
$H{}^{13}COOOH$		$H{}^{13}COOH$ and H_2O_2
$HC{}^{18}OOOH$		$HC{}^{18}O{}^{18}OH$ and H_2O_2
$HCO{}^{18}OOH$ $HCOO{}^{18}OH$ $HCO{}^{18}O{}^{18}OH$	in 1:1:1-mixture	$HCOOH$ and $H_2{}^{18}O_2$ (50 atom-% ${}^{18}O$)

out behind safety shields. In order to reduce decomposition, peroxyformic acid was stored in a 5-liter glass bulb in gaseous form at a pressure of less than 15 Torr. No attempt was made to further purify the samples from *Reaction 3*. They contained traces of water, formic acid and H_2O_2.

Experimental. - a) *Preparation of concentrated solutions of [^{18}O]hydrogen peroxide.* Potassium *t*-butoxide (3.33 g, 30 mmol), which was freshly sublimed at 0.05 Torr and 150–170°, was placed in a three-necked round-bottom flask and attached to a vacuum line. The flask was then cooled with an ice-water mixture. After evacuation to less than 20 mTorr, $^{18}O_2$-gas (*Ventron GmbH*, 7500 Karlsruhe, Germany; 50 atom-% ^{18}O, randomized mixture, *i.e.* 1:2:1) was introduced up to a pressure of 450 Torr. A solution of 5.52 g (30 mmol) benzhydrol (*Fluka, purum*) in 40 ml ether (thoroughly dried over Na/Pb-alloy) was added dropwise over a period of 5 to 10 min under constant magnetic stirring. During addition of the ether solution the pressure at first rose to 650 Torr and then decreased due to the consumption of $^{18}O_2$ by the reaction according to *Equation 1*. The *t*-BuOK dissolved yielding a clear yellowish solution. When the pressure had dropped below 300 Torr, more $^{18}O_2$-gas was introduced in portions until a pressure of 700 Torr was reached. After 8 to 10 additions over about 60 min the stoichiometric amount of $^{18}O_2$ had been introduced and the reaction mixture consumed no more $^{18}O_2$. A yellowish precipitate of potassium hydroperoxide had been formed during the reaction which was now filtered off through a cooled glass filter. The precipitate was washed three times with dry, cold ether and dried at 0° *in vacuo*. A yield of 1.9 g (83%) potassium hydroperoxide was obtained. It was stored at dry ice temperature and showed no signs of decomposition.

The finely crushed potassium hydroperoxide was placed in a test tube with a magnetic bar and cooled to ice temperature. HCl (1.3 ml, 2N) was then added dropwise. To this mixture, conc. HCl was added until the pH reached a value below 4. The colorless liquid which contained a white precipitate and some oily drops was extracted twice with 4 ml $CHCl_3$ and centrifuged. The supernatant aq. solution was pipetted into an ampoule and stabilized by adding a few crystals of sodium stannate and tartaric acid [13]. Subsequently the mixture was separated from inorg. and org. salts by a gas-phase transport in the vacuum line at a pressure of 20 mTorr and collected in a second ampoule; 2.4 g of a clear, colorless solution was collected with a content of 19% H_2O_2 (the content was determined by a $KMnO_4$-titration [14]). This corresponds to a yield of 40% referred to gas consumption. The solution was again stabilized and transferred to a microdistillation apparatus shown in the *Figure*. The solution

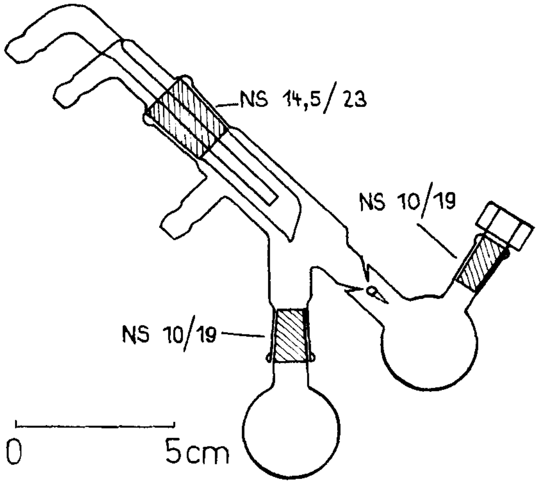


Figure. *Microdistillation apparatus*

was cooled to 0° and stirred using magnetic stirring. After evacuation with a water jet pump the temperature was allowed to rise to r.t. Over 3 h it was then raised to 30° by warming with a water bath. The condensation trap was constantly maintained at ice-temperature. About 70% of the water was distilled off. The remaining clear and colorless solution (0.5 ml) contained 70% H_2O_2 [14]. Due to the randomized gas mixture it contained 25% [$^{18}O_2$]hydrogen peroxide, 25% [$^{16}O_2$]hydrogen peroxide and 50% [$^{18}O^{16}O$]hydrogen peroxide. This sample could be stored at $-25°$ for more than one week without loss of active oxygen.

b) *General method for the synthesis of peroxyformic acid.* Either 150 µl (2.8 mmol) H_2SO_4 (91%) or 153 mg (3.5 mmol) metaboric acid [12] were placed in an ampoule and cooled to 0°. H_2O_2 (8.9 mmol) in water (minimum content 50%) and 3.0 mmol formic acid (minimum content 95%) were then added dropwise. The ampoule was attached to a vacuum line and allowed to stand for 1 h at ambient temperature. The mixture was then cooled to liquid nitrogen temperature and thoroughly evacuated with a rotary pump. Upon warming up to r.t. peroxyformic acid expanded into a 5-liter glass bulb attached to the vacuum line reaching a final pressure of 10 Torr.

Peroxyformic acid and its isotopically labelled species were characterized by their microwave spectra. Details of measured transition frequencies and rotational constants are reported in [1]. In addition the matrix infrared spectrum of peroxyformic acid was recorded. – IR. (Ar-matrix): 1737*s*, 1437, 1334, 1114*s*, 857, 810, 441, 352, 342.

c) *Synthesis of individual isotopically labelled peroxyformic acids.* – *[O-^{2}H]peroxyformic acid.* Metaboric acid had to be deuterated first in order to avoid unnecessary dilution of the isotopic purity. Orthoboric acid (0.5 g, 48 mmol) was dissolved in 2.5 ml (125 mmol) warm ^2H_2O (99.8 atom-% ^2H). Water was distilled off under vacuum. The deuterated orthoboric acid was heated *in vacuo* at 90° to obtain deuterated metaboric acid [12]. A highly concentrated solution of $^2H_2O_2$ was prepared in the microdistillation apparatus (see the *Fig.*) from a commercially available sample (*Chemische Fabrik Uetikon*, 30% $^2H_2O_2$ in ^2H_2O with 98 atom-% ^2H). The synthesis of [O-^{2}H]peroxyformic acid proceeded along the general method using deuterated metaboric acid, deuterated H_2O_2 and formic acid.

[C-^{2}H]peroxyformic acid. The general method was followed starting from $^2HCOO^2H$ (*Elektrochemie Turgi*, 98%, 99.4 atom-% ^2H in ^2H_2O) and H_2O_2.

[^{13}C]peroxyformic acid. The synthesis was carried out with $H^{13}COOH$ (*MSD Isotopes*, 90 atom-% ^{13}C) and H_2O_2.

[C-^{18}O]peroxyformic acid. The K-salt of [^{18}O]formic acid was prepared by the base-catalyzed hydrolysis of KCN in $H_2{}^{18}O$ (99 atom-% ^{18}O) according to the method of *Grant & Turner* [16]. The acid was liberated from its dried K-salt by the action of gaseous HCl. [^{18}O]formic acid and H_2O_2 were used to synthesize [C-^{18}O]peroxyformic acid according to the general method.

[C-^{18}O-^{18}O]-, [C-^{18}O-^{16}O]- and [C-^{16}O-^{18}O]peroxyformic acid. A mixture of these compounds together with unlabelled peroxyformic acid was obtained from a concentrated solution of [^{18}O]hydrogen peroxide (50 atom-% ^{18}O, see *Section a)* and formic acid in the presence of sulfuric acid.

Discussion. – Concentrating aq. H_2O_2-solutions by evaporation of water under vacuum is often prevented by decomposition of the solution due to traces of metal ions or organic material. These traces are known to promote or initiate decomposition and, once started, the decomposition reaction cannot be stopped. The synthetic procedure of *Sawaki & Foote* [10] for the preparation of ^{18}O-labelled H_2O_2 was slightly modified to produce solutions of more than 10% H_2O_2-content in water. Solutions of up to 70%-content were obtained after careful minimization of organic and inorganic impurities and subsequent evaporation of water *in vacuo* in the presence of stabilizers. The solutions were successfully used for the synthesis of peroxyformic acid labelled in the peroxy group. The positions of the isotopic substitution in all labelled acids were checked by their microwave spectra. The results were consistent with the *Equilibrium reaction 3* being a simple substitution of the hydroxyl- by the hydroperoxy-group and *vice versa*. With the exception of the deuterium in $HCOOO^2H$ no dilution or randomization of the isotopic labelling occured. Deuterium was there easily exchanged against hydrogen by traces of water. In order to suppress possible exchange the storage bulb and the microwave absorption cell were treated with gaseous ^2H_2O.

Financial support by the *Swiss National Science Foundation* is gratefully acknowledged. We are greatly indepted to Dr. *Geiger, Chemische Fabrik Uetikon,* for a gift of deuterated hydrogen peroxide. Finally, we wish to thank Dr. *H. Hollenstein* and *M. Rodler* for helpful discussions and Dr. *T. Beech* for carefully reading the manuscript.

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