AN IMPROVED METHOD OF HYDROGEN ISOTOPIC EXCHANGE WITH DEUTERIUM SULFATE, AND THE PREPARATION OF 9,10-ANTHRAQUINONE-d_8[1]

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ABSTRACT

An apparatus and improved conditions are described for using easily and efficiently sulfuric acid-d_2 as a deuterating agent. The preparation of 9,10-anthraquinone-d_8 with a high deuterium content is reported.

In a study of the vibrational spectrum of anthraquinone,[2] it was necessary to prepare anthraquinone-d_8 with high deuterium content. A careful consideration of the possible methods (1) convinced us that isotopic exchange would be the most convenient if a proper exchange agent could be found. The high stability of anthraquinone to concentrated sulfuric acid suggested the use of sulfuric acid-d_2.

Several deuterated aromatic compounds have been prepared by exchange with D_2SO_4 (2–7), but the operating conditions and yields are not always satisfactory. An examination of the methods used indicates that the disadvantages of using sulfuric acid-d_2 are to an important extent related to its activity as a sulfonating agent. Conditions for the isotopic exchange of a particular compound with sulfuric acid-d_2 are a concentration of the acid and a temperature at which the sulfonation rate is considerably lower than the exchange rate (5, 6). Such conditions are often attained at comparatively low temperatures and concentrations of sulfuric acid-d_2. These conditions (8) and the low solubility of the compound in sulfuric acid-d_2 (7) lead to low exchange rates. It is therefore necessary to use long exchange time and to renew the acid several times.

Because sulfonation is a reversible reaction, however, these difficulties can be avoided. The exchange can be allowed to take place at high temperature and high concentration of sulfuric acid. Under these conditions the exchange rate is high. After the exchange, the reaction mixture can be treated to hydrolyze the sulfonic acids formed. Because the solubility of many aromatic compounds is low in dilute, but appreciable in concentrated sulfuric acid, the presence of an organic solvent is not necessary (4, 6).

To apply this technique, we used an apparatus in which it is possible to obtain a gradient of both temperature and sulfuric acid concentration. The required quantity of sulfuric acid-d_2 was quite small. The method gave the fully deuterated product in high yield and isotopic purity, as shown by mass spectral analysis.

In our opinion, the procedure here described permits extension of the use of sulfuric acid-d_2, which is easy to handle, as a deuterating agent for aromatic compounds that do not undergo irreversible reactions (e.g. oxidation) under exchange conditions.

EXPERIMENTAL

Starting Materials

The anthraquinone used was a C. Erba (Milan) RP product, and the deuterium oxide was a Fluka "purissimum" product with a deuterium content of 99.7%.

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[2] *C. Pecile and B. Lunelli. To be published.*

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Preliminary Experiments on the Exchange between Anthraquinone and Sulfuric Acid-d_2

An appreciable amount of anthraquinone dissolves in sulfuric acid of concentration higher than 80% (9), and gives oxonium salts (10). Sulfonation requires somewhat drastic conditions (11), and monosubstitution takes place principally in the β position, or in the α position if mercury salts are present. At temperatures above 230 °C, there is appreciable disulfonation and oxidation to polyhydroxylated compounds (11, 12).

Since for several aromatic compounds the exchange rates of hydrogen isotopes are appreciable at concentrations and temperatures lower than those required for sulfonation (2–7), we kept 500 mg of anthraquinone, dissolved in 5 ml of 95% D_2SO_4 (in D_2O), at 160 °C overnight. The infrared spectrum of the recovered anthraquinone (m.p. 286 °C, recrystallyzed from benzene) indicated that exchange had taken place and that no anthraquinone-d_0 was present.

To obtain larger quantities of deuterated anthraquinone, we allowed exchange and desulfonation to take place separately, in successive steps. Anthraquinone (2 g), deuterium oxide (5.5 ml), and sulfuric acid-d_2 (6.6 ml) were introduced into one arm of an inverted Y-shaped glass tube, which was then sealed under vacuum. The arm containing the mixture was heated until 5 ml of distillate had been collected in the other arm, kept at 0 °C. The arm containing the solution of anthraquinone in concentrated sulfuric acid was then kept for 20 min at 160 °C, cooled to room temperature, and poured slowly into the water which had distilled.

The same procedure[3] was repeated 4 times on the thick suspension obtained, then the apparatus was opened, 200 mg of mercury oxide were introduced, and the procedure was repeated 5 times more. Finally the whole apparatus was kept at 140 °C for 2 h, then opened; the anthraquinone was filtered off, and recrystallized from benzene. The series of 10 distillations, with introduction of mercury oxide after the fifth, was repeated twice more on the same sample, each time with fresh deuterium sulfate and deuterium oxide. At the end of these operations, 1.1 g of recrystallized anthraquinone, m.p. 286 °C, were obtained. With the quantities of reagents that were used, if we assume that the partition coefficient for deuterium between anthraquinone and sulfuric acid is 1 (6), the anthraquinone obtained in this experiment should have had a deuterium content of 99.7%. Its infrared spectrum, however, showed a number of weak bands which, when compared with the

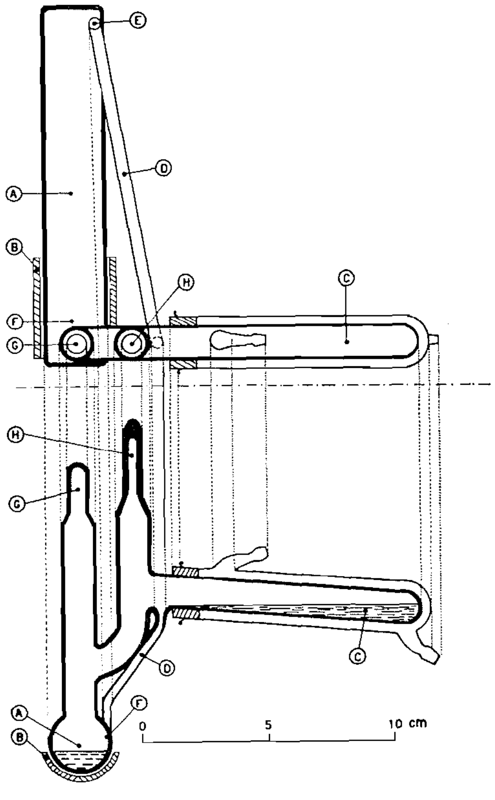

FIG. 1. Apparatus for the preparation of 9,10-anthraquinone-d_8.

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[3] *At the beginning of each distillation, the concentration of sulfuric acid is low, and desulfonation takes place; at the end, the concentration is high, and both exchange and sulfonation of anthraquinone occur.*

spectra of the anthraquinone obtained at intermediate stages of the exchange, were recognized as having originated from partially deuterated anthraquinones.

This indication of low isotopic purity implied either that the partition coefficient for deuterium between anthraquinone and sulfuric acid-d_2 is less than 1, or that equilibrium distribution had not been attained. The latter seems more probable, since when the solution of anthraquinone in concentrated sulfuric acid is poured into the water, anthraquinone separates in finely divided form giving a thick suspension. This might limit mixing and therefore hydrogen isotope exchange between sulfuric acid and water. Moreover, since the partial rate factors for the exchange between anthraquinone and sulfuric acid were not known, the period allowed for exchange might have been too short.

These disadvantages and the long time required by this procedure induced us to seek another method. We designed an apparatus in which exchange sulfonation and desulfonation could take place at the same time, the reactions occurring in two separate parts of the apparatus.

Apparatus and Operating Conditions

The apparatus is made of borosilicate glass tubing. Figure 1 is a diagram of it.

The mixture of anthraquinone, deuterium sulfate, and deuterium oxide is placed in tube A. A small flame is placed under piece B (made of aluminium sheet 3 mm thick) and the water vapor produced condenses in C, which is cooled by flowing water. The condensate then flows down tube D and through E enters tube A, where it mixes with the solution of anthraquinone in sulfuric acid.

By varying the inclination of condenser C, it is possible to regulate the quantity of water held in it. An increase in the quantity of water held in C results in an increase in the concentration of the sulfuric acid in A, which causes the temperature of the mixture to rise. When the system reaches a steady state, there is a gradient of both temperature and sulfuric acid concentration from E to F. Near F, where the acid is concentrated, exchange and sulfonation of the anthraquinone occur; near E at the same time desulfonation of anthraquinone and exchange between sulfuric acid and water occur.

Several experiments were made with this apparatus to establish the proper operating conditions. It was found that the presence of mercury salts reduces considerably the quantity of recovered anthraquinone but

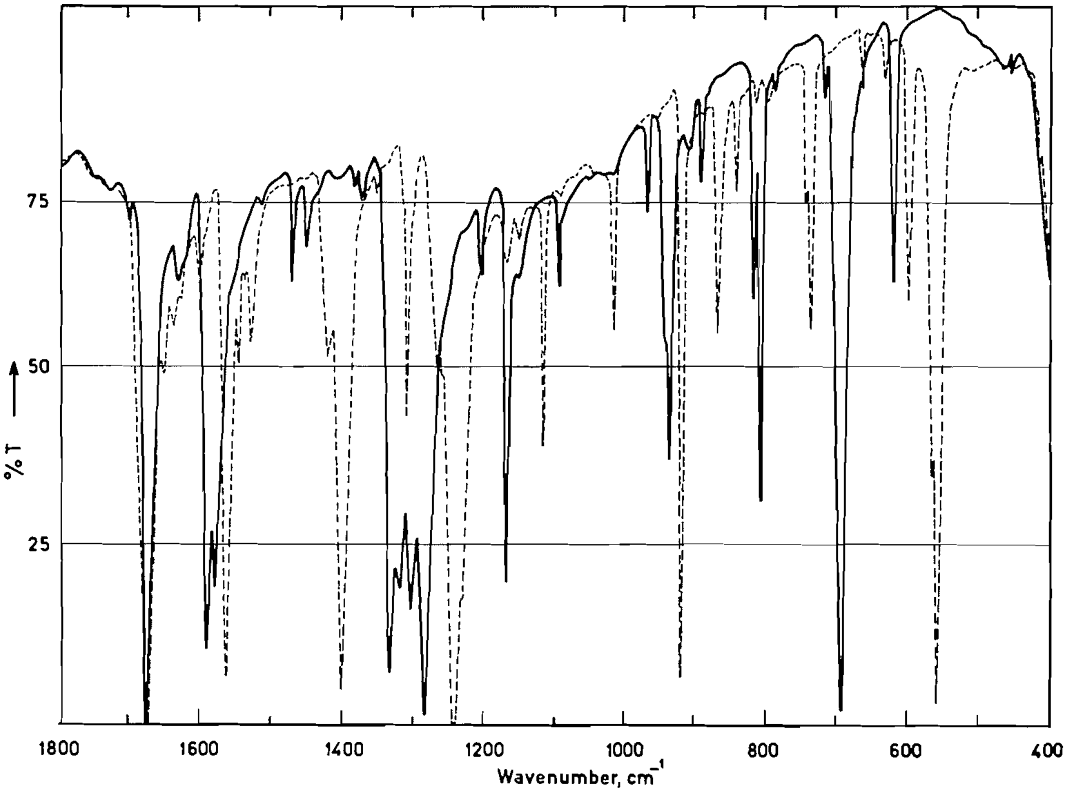

FIG. 2. Infrared spectra of 9,10-anthraquinone-d_0 (solid line) and 9,10-anthraquinone-d_8 (broken line) in KBr pellets (1 mg + 200 mg KBr). The spectra were measured on a Beckman model IR9 spectrometer.

has no influence on the degree of deuteration, and that an exchange period of $2\frac{1}{2}$ h is sufficient for the attainment of equilibrium in hydrogen isotope distribution.

Preparation of Anthraquinone-d_8

An apparatus with the dimensions indicated in Fig. 1 was thoroughly degassed under vacuum, filled with dry nitrogen, and placed in a dry box. Anthraquinone (2 g) was melted in a thin glass tube, which was then broken; the compound was thus obtained free from moisture and in the form of a cylinder. It was introduced into the apparatus through tube G, which was then sealed. Deuterium oxide (5.4 ml) and deuterium sulfate (6.6 ml) were put in through tube H with a long hypodermic needle. The apparatus was immersed in liquid nitrogen and evacuated, and tube H was sealed. The apparatus was removed from the dry box, and heated for $2\frac{1}{2}$ h. Because of the relatively high vapor pressure of anthraquinone at the temperatures of operation, it was necessary to discontinue heating every 30 min, and melt with a flame the anthraquinone which had sublimed on the walls. The indicated period of $2\frac{1}{2}$ h does not include the time during which heating was stopped for this. The apparatus was then allowed to stand for 2 h at 130 °C in an oil bath, cooled to room temperature, and opened at G. The mixture of anthraquinone and 70% sulfuric acid was poured onto a sintered glass funnel in which a 3 mm layer of powdered glass had been placed, and filtered with suction. The product was washed repeatedly with sodium bicarbonate solution until the filtrate was no longer acid. Then it was dried, and crystallized twice from benzene with the addition of a little active charcoal. By this procedure, a yield of 1.8 g, m.p. 286 °C was obtained.

The procedure was repeated two more times. Finally, 1.4 g (yield 70%) of product, m.p. 286.8–287.2 (corr.) was obtained. The infrared spectrum is shown in Fig. 2 together with that of the light compound. The infrared spectrum of the product obtained after two exchanges differs from that indicated in Fig. 2 only by the presence of a few weak additional bands. The intensities of the C—H and the C—D stretching bands is very low and do not permit an estimate of the degree of deuteration.

The mass spectrometric analysis of the final product, made by Merck Sharp and Dohme of Canada Ltd., gave anthraquinone-d_8 95.38%, anthraquinone-d_7 4.62%, total deuterium 99.42%.

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