Chemistry of Vitamin E. XXXVII. The Amperometric Titration of α-Tocopherol with Auric Chloride at the Dropping Mercury Electrode[1]

BY LEE IRVIN SMITH, I. M. KOLTHOFF AND LEO J. SPILLANE

Although α-tocopherol can be determined polarographically,[2] the measurement of the diffusion current of its anodic wave is somewhat complicated. This is due to the fact that the current is measured over a very narrow potential range, which lies near the anodic dissolution point of mercury. The residual current, therefore, is appreciable, and the polarographic determination is subject to an error of 3 to 5% in 0.001 M solutions. Moreover, the composition of the buffer affects the magnitude of the diffusion current.[2] Amperometric titrations,[3] in general, yield much more accurate results than do polarographic determinations, especially when the solutions are very dilute.

Karrer and his collaborators[4] found that α-tocopherol was quantitatively oxidized to tocopheryl quinone by auric chloride, and these authors used this reagent in the potentiometric titration of α-tocopherol and related compounds.

$$3 \text{ (structure)} \quad C_{16}H_{33} + 2AuCl_3 + 3H_2O \longrightarrow$$

$$3 \text{ (structure)} \quad CH_2CH_2CC_{16}H_{33} + 2Au + 6HCl$$
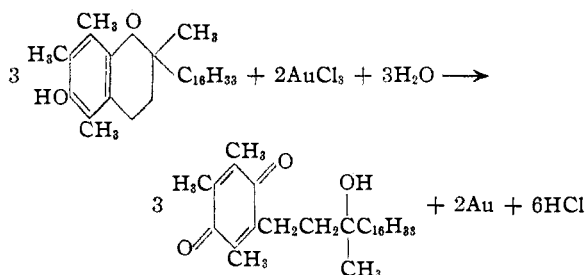
The use of auric chloride in the amperometric titration of α-tocopherol, with the dropping mercury electrode as indicator electrode, has now been studied.

Apparatus

The cell and the equipment were similar to those described previously.[2] Provision was made for removal of the mercury dropping from the electrode, in order to prevent it from reacting with an excess of gold chloride.

The capillary used had the following characteristics. In 0.1 M potassium nitrate, containing 0.001 M nitric acid, and under a pressure of 62.7 cm. of mercury, $t = 3.72$ sec. (open circuit), $m = 1.52$ mg. sec.$^{-1}$, and hence $m^{2/3}t^{1/6} = 1.646$.

The specimen of synthetic dl-α-tocopherol was prepared by condensation of phytol with trimethylhydroquinone.[5,6]

The reagent was a standard solution of chloroauric acid (HAuCl$_4$·3H$_2$O), 0.00979 M in 75% ethanol. The solution was standardized by two accepted methods involving reduction of the chloroauric acid to metallic gold. In one method ferrous sulfate was used as the reducing agent; in the other, oxalic acid.[7]

Experimental

In general, a weighed sample of the tocopherol was dissolved in a small amount of 95% ethanol. The solution was transferred to the electrolysis cell, and the container was washed with a solution of the supporting electrolyte in 75% ethanol. The solution in the cell was diluted with the supporting electrolyte to a volume of 90 ml. The cell was placed in a thermostat and nitrogen was passed through the solution for twenty to twenty-five minutes to remove dissolved oxygen. Connection was then made, by means of a salt bridge, with a saturated calomel electrode, and the titration was performed at the desired applied potential. The reagent was added, in portions, from a buret, and a current of nitrogen was passed for a minute or two through the mixture in the cell after each portion of the reagent was added.

Discussion of Results

Several experiments were carried out in 0.1 N potassium chloride as the supporting electrolyte. The current–voltage curve of auric gold in this medium showed a pronounced maximum (Fig. 1), which was not suppressed by methyl red. At a potential of −0.2 v. (vs. S. C. E.) the diffusion current was reached, and this was found to be proportional to the concentration of gold. The amperometric titration of α-tocopherol was carried out at an applied potential of −0.4 v. Before the end-point of the titration, a period of at least five minutes was required, between additions of gold chloride solution, for the current to become constant. Apparently the reaction between α-tocopherol and the reagent was slow, in the medium used, even at 35°. After the end-

(1) Paper XXXVI, THIS JOURNAL, 64, 644 (1942).

(2) Smith, Spillane and Kolthoff, ibid., 64, 447 (1942).

(3) Kolthoff and Lingane, "Polarography," Interscience Publishers, Inc., New York, N. Y., 1941, p. 447.

(4) Karrer, Escher, Fritzsche, Keller, Ringier and Salomon, Helv. chim. acta., 21, 939 (1938).

(5) Smith, Ungnade, Stevens and Christman, THIS JOURNAL, 61, 2615 (1939).

(6) The authors wish to thank Dr. R. T. Major and Merck and Company, Inc., Rahway, N. J., for a gift of the synthetic tocopherol used in these experiments.

(7) (a) Hillebrand and Lundell, "Applied Inorganic Analysis," John Wiley and Sons, Inc., New York, N. Y., 1929, p. 288. (b) Scott, "Standard Methods of Chemical Analysis," Vol. I, D. Van Nostrand Company, Inc., New York, N. Y., 1925, p. 230. (c) Treadwell and Hall, "Analytical Chemistry," Vol. II, John Wiley and Sons, Inc., New York, N. Y., 1935, p. 250.
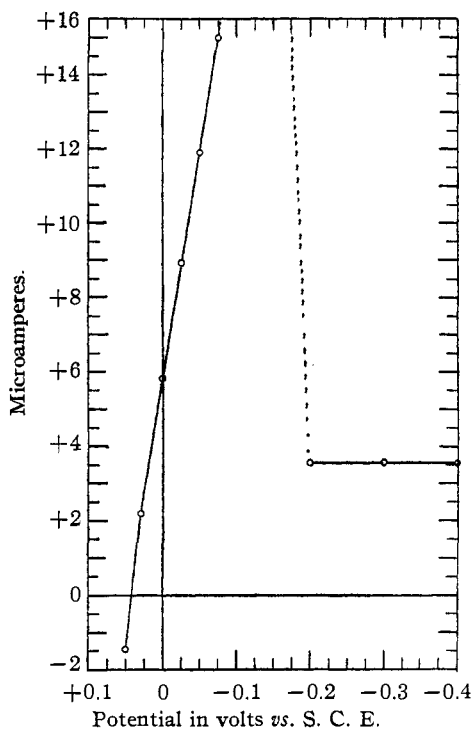
Fig. 1.—0.490 × 10⁻³ M AuCl₃ in 0.1 M KCl in 75% ethanol.

point was reached, the current became constant immediately after each addition of reagent. When the values of the current (corrected for the dilution effect) were plotted against the volume of reagent added, two straight lines were obtained, as shown in Fig. 2. The increase of the current, up to the point of intersection of the lines, is due to the diffusion current of α-tocopheryl quinone. In a previous study[1] it has been shown that this quinone yields a diffusion current at −0.4 v. Titrations carried out in the manner described, with 20 to 40 mg. quantitites of α-tocopherol, yielded results which were 12.5 to 20% high. The error may be due partly to incomplete oxidation of the tocopherol before the point of intersection of the lines and partly to the change of pH during the titration. Since the angle between the two lines is very obtuse (Fig. 2), the point of intersection cannot be found with great accuracy, when the supporting electrolyte is 0.1 N potassium chloride.

Titrations were carried out in buffer solutions in order to maintain the following conditions: constant pH, a potential at which tocopheryl quinone would not be reduced, and at which gold would yield a diffusion current. Under such circumstances the measured current should re-

main equal to the residual current of the medium until the end-point, and then it should increase in a linear manner with an excess of gold. Several experiments were performed in a sodium acetate–acetic acid buffer in 75% ethanol. The results were 25 to 30% high. This error was caused by the precipitation of gold from a solution of auric gold, by excess sodium acetate.
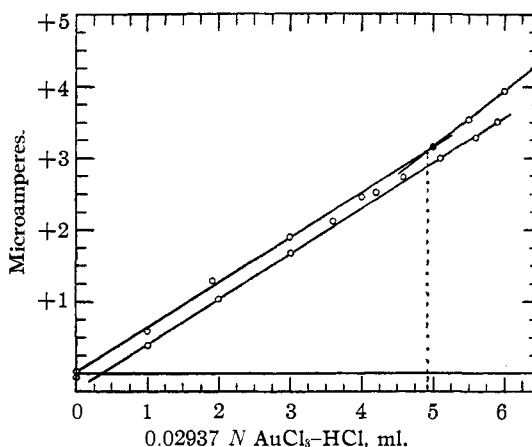

0.02937 N AuCl₃–HCl, ml.

Fig. 2.

It was necessary, therefore, to find a buffer which was soluble in 75% ethanol, and which would react very slowly, if at all, with auric gold. The best results were obtained in a benzoic acid–sodium benzoate buffer in 75% ethanol, which was 0.1 M in benzoic acid, 0.1 M in sodium benzoate, and 0.1 M in sodium chloride. Sodium chloride was added in order to stabilize the gold solution by conversion of more of the gold chloride into the chloroaurate complex. The spontaneous decomposition of auric gold in this buffer was slow, and did not interfere with the titrations. The current–voltage curve of gold in the benzoate buffer did not show a maximum, and the diffusion current was obtained at a potential of −0.075 v. ($vs.$ S. C. E.). This diffusion current was found to be proportional to the gold concentration. The diffusion current decreased slowly

TABLE I

AMPEROMETRIC TITRATION OF α-TOCOPHEROL WITH 0.979 × 10⁻² M AURIC CHLORIDE

Buffer: 0.1 M sodium benzoate, 0.1 M benzoic acid, 0.1 M sodium chloride in 75% ethanol.

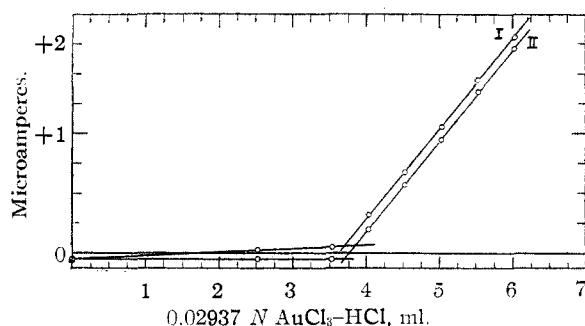| E_0 ($vs.$ S. C. E.), v.	Temp., °C.	End-pt., ml.	Time, min.	α-Tocopherol, mg. Found	Weighed
−0.100	30	3.70	>50	23.36	23.29
− .075	30	3.70	>50	23.36	23.29
− .075	35	4.21	35	26.58	26.61
− .075	35	2.47	35	15.60	15.59
− .075	36	6.57	50	41.49	41.49

Fig. 3.—Amperometric titration of α-tocopherol in 0.1 M benzoic acid–0.1 M sodium benzoate–0.1 M sodium chloride in 75% ethanol: I, applied potential -0.100 volt; II, applied potential -0.075 volt.

as the solution stood, because of spontaneous reduction of auric gold, but the decrease was no more than 2 to 3% at the end of twenty minutes and it did not appear to affect the titration. At a potential of -0.075 v. the tocoquinone was not reduced, and its reduction at -0.1 v. is negligibly small. Table I gives the results of several titrations.

Two straight lines were obtained, as shown in Fig. 3. Since the tocoquinone was not reduced at a potential of -0.075 v., only a few readings needed to be made before the end-point. This shortened the time of a titration considerably, and hence the titration could be carried out within thirty to thirty-five minutes. From the data in Table I it follows that α-tocopherol can be determined, with an accuracy of 0.3%, in a concentration range between 1×10^{-3} and 3×10^{-4} M.

A few amperometric titrations in the benzoate buffer were made with 2,5,7,8-tetramethyl-6-hydroxychroman but the results were about 2% high.

Summary

α-Tocopherol, in 75% ethanol solution, can be determined rapidly, precisely, and accurately in very low concentrations, by amperometric titration. The dropping mercury electrode is used as an indicator electrode and the solution is titrated with auric chloride. The best buffer found is one which is 0.1 M with respect to benzoic acid, sodium benzoate, and sodium chloride.

The Kinetics of the Hydrogen Fluoride Catalyzed Reaction between Toluene and t-Butyl Chloride

BY J. W. SPRAUER AND J. H. SIMONS

The recently demonstrated catalytic activity of hydrogen fluoride in promoting condensation reactions[1] has focused attention on the mechanism of such reactions. Kinetic studies can be most readily accomplished and interpreted provided the following conditions are met: (1) the reaction is quantitative, (2) a physical means is available for the determination of the progress of the reaction, (3) the rate is such at an easily controllable temperature that it can be readily determined, and (4) the reaction is homogeneous. The reaction between toluene and t-butyl chloride to form t-butyltoluene and hydrogen chloride when catalyzed by hydrogen fluoride was found to satisfy the above conditions.

Kinetic experiments were accomplished by varying the concentration of the reactants and the catalyst. The rate of reaction was found to be first order with respect to t-butyl chloride concentration, to be retarded according to an inverse linear function of the hydrogen chloride pressure, to be catalyzed according to a high order of hydrogen fluoride pressure and to be strongly promoted by small amounts of water and methanol. These facts and other details of the kinetic results as well as the known descriptive chemistry of this reaction have been correlated on the basis of postulated mechanisms.

Preparation of Materials.—Hydrogen fluoride was prepared by the method described by Simons.[2] It was stored in a copper vessel and was withdrawn for use as the gas.

t-Butyl chloride was prepared from technical t-butanol and c. p. hydrochloric acid, dried over anhydrous sodium carbonate, and fractionated through an eight to ten plate glass-packed laboratory column. The middle sixty per cent. which ·had a constant boiling point and refractive index was retained, $n^{18}D$ 1.3860 observed, 1.3868 in literature. It was stored over anhydrous sodium carbonate and carefully pipetted for use.

(1) Simons, et al., THIS JOURNAL, **60**, 986, 2952, 2953, 2955, 2956 (1938); **61**, 1521, 1795, 1821 (1939); **62**, 451, 485, 1623, 1624 (1940); **63**, 608, 880, 1921 (1941).

(2) Simons, ibid., **46**, 2179 (1924).