HIGH-FREQUENCY METHODS IN ORGANIC ANALYSIS

(REVIEW)

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High-frequency methods for the analysis of organic compounds [1-9] are being more widely used, because they possess well known advantages and because they make possible the automation of production control or of various physico-chemical measurements [10]. With similar or much less complicated apparatus, as compared with that required for potentiometric or conductometric analysis, it is often possible by the high-frequency method to determine, with adequate precision, the contents of individual components in complex organic mixtures [11-13].

We give below a review of the literature on the high-frequency titration of organic compounds, in aqueous and nonaqueous media, published in the period 1956-1962.*

Titration in Aqueous Media

All the reactions used in conductometric analysis can also be used for high-frequency titration in aqueous media, since the reading of a high-frequency instrument will give the change in specific electrical conductivity during the titration process [15].

In many cases the high-frequency titration of an aqueous solution of a weak organic acid with a strong base gives an ill defined end-point, and this reduces the analytical precision. This effect is associated with the buffering action and hydrolysis of the highly dissociated salts formed in the reaction. The left "acid" branch of the titration curve may even tend upwards and form an obtuse angle with the right "alkaline" branch of the curve. This type of curve is obtained if the fall in electrical conductivity resulting from the neutralization of H^+ ions is compensated for by an increase resulting from the rise in concentration of well discussed Na^+ salt.

A method of reverse high-frequency titration [16] can be used to increase the analytical precision by suppressing hydrolysis. In this, the solution of weak acid to be analyzed is first treated with a slight excess of a standard base solution, and the titration is then carried out with a strong acid. In the case of phenol, for example, curves with two clearly defined breaks are obtained, the first corresponding to the content of free base in the solution, and the second to the final titration of sodium phenolate (Fig. 1). In this way it is possible to determine 0.02 to 0.05 g of phenol with a precision of about 1%. The same method has been used for titrating enols and amides [17], which are first treated with lithium hydroxide and then titrated with hydrochloric acid solution. Such titration curves of polybasic acids also show two sharp breaks, characteristic of monobasic acids, whereas, on titration with caustic soda, a dibasic phenol behaves as a weak dibasic acid and gives an ill defined second break.

The back titration method in an aqueous medium has also been used for determining the sum of meta-, ortho-, and para-cresols; as in the previous case [16], the content of each isomer is determined from the difference between two volumes corresponding to a first and second break in the titration curve (Fig. 2). This back titration method is now widely used for the high-frequency titration of various weak organic acids.

Under appropriate conditions the direct titration of organic acids with alkali, or of organic bases with acid, can also give quite satisfactory results. Thus, methods have been developed for determining acetic and sulfuric acids in acetylating mixtures, α-methylpyridine (α-picoline) in mixtures with formalin, basic material in pyridine-ethanol, aromatic sulfonic acids (toluenesulfonic acid, benzenesulfonic acid, etc.), for the separate determination of benzene-

* Work up to 1956 is reviewed in [4, 14].

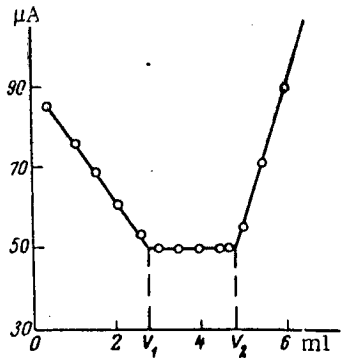

Fig. 1. Titration of sodium phenolate with 0.1 N HCl solution: V_1 is the acid consumed in titration of the free alkali, ml; V_2 is the acid consumed in titration of the phenolate, ml.

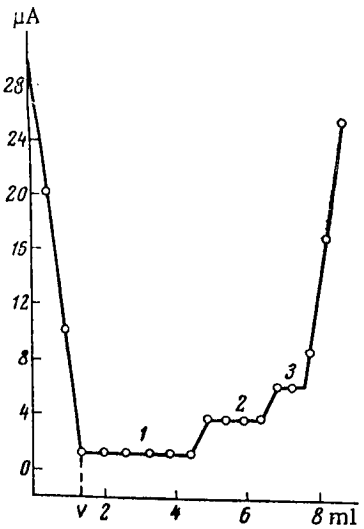

Fig. 2. Titration of a mixture of sodium cresolates with 0.1 N HCl solution: V is the acid consumed in titration of the free alkali, ml; the steps 1, 2, and 3 correspond to the hydrochloric acid consumed in the titration of o-, p-, and m-cresols respectively.

sulfonic acid in mixtures with sulfuric acid, etc. [18]. The titration of hydrochloric acid, formed by the interaction of hydroxylamine hydrochloride with formaldehyde, can be used for determining the latter in the production of phenol-formaldehyde resins; a method has been developed for the analysis of α-polyhydroxymethylene on this basis [19].

Direct titration with sulfuric acid has been used for the determination of pyridine and aniline in phenols [20]; determination of these impurities by other means was found to be impossible owing to the presence of emulsions in the solution [15].

Precipitation reactions have been used for the titration of melamine with cyanuric acid in the presence of impurities (ameline, urea, biuret, etc.), with a precision of ±0.5% in a period of 40 min, and for the titration of cyanuric acid with melamine [21]; for the determination of fluorine in fluoropolymers containing chlorine (after mineralization of the sample), by titration with calcium acetate (precision about 1%, time about 1 h) [22, 23]; for the determination with sodium tetraphenylborate. The last method gives high results, attributed by the authors to nonlinearity of the characteristic curves [24, 25].

Complexometric high-frequency titration has been used for determining hydroxytetracycline (terramizine) [26]. The solution to be analyzed is the first break in the curve corresponds to titration of the excess ferric ion, and the second break to titration of the terramizine-iron (1 : 1) complex.

It is well known that kinetic methods of analysis have now acquired considerable importance for the determination of ultrasmall amounts of substances [27]. It has been shown that the high-frequency method can be used for the determination of acetylacetone by measuring its rate of reaction with hydroxylamine hydrochloride [28]. The change in electrical conductivity of the system in the course of the reaction is registered and recorded automatically. The mean precision for analysis of the pure substance is 0.3%, but is somewhat lower in the presence of inert electrolytes. A particular advantage of the method is that it can be used for reactions which do not go to completion.

Various other papers give data on the high-frequency titration of organic compounds in aqueous solution: the determination of lactic acid in mixtures with hydrochloric acid and chlorides [29], and the determination of alkaloids [30] and other compounds [31-35].

Nonaqueous Titration

Materials for organic analysis are often weak acids, bases, or their salts, which have similar or equal dissociation constants in water. High-frequency titration of a mixture of such compounds in aqueous solution gives a titration curve showing only one equivalent point, corresponding to the total, so that it is impossible to determine the components separately. In this case it is an advantage to use an organic solvent, or solvent mixture, for the titration and the titrant. Weak organic acids are usually titrated in basic solvents, such as ethylenediamine, dimethylformamide, pyridine, etc., using an inorganic or organic base in a suitable nonaqueous solvent as titrant. For weak organic bases it is normal to use a protogenic solvent, such as acetic acid or formic acid, and to titrate with a strong mineral or organic acid. However, neutral solvents, such as ketones, alcohols, hydrocarbons, etc., are often used in high-frequency titrations.

In order to obtain a clear indication of the end point on the high-frequency titration curve, the solvent and titrant should be selected so that the electrical conductivity of the solution to be titrated alters as much as possible as the result of the reaction, and shows a marked change at the end point [36]. However, the present state of the theory of nonaqueous solutions does not make it possible to predict the best solvent, or mixture of solvents, to satisfy

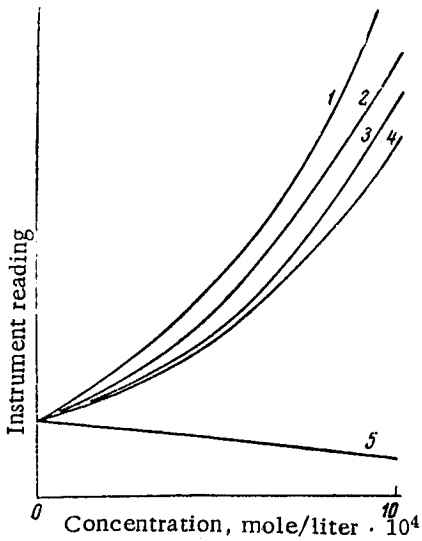

Fig. 3. High-frequency characteristic curves for the methylates of alkali metals in dimethylformamide: 1) Cesium; 2) rubidium; 3) potassium; 4) sodium; 5) lithium.

the above condition. In general, the medium for nonaqueous titration is selected empirically, and this accounts for the complex compositions sometimes used [37].

In this connection, great value attaches to the work of N. A. Izmailov and his coworkers [38-41], who showed that the strengths of acids, bases, and salts depend on the nature of the solvent used. The differentiating action of a solvent, for acids and bases, is often used in analytical practice, and particularly in high-frequency titration [14, 42].

In the same connection, there is an interesting paper in which an attempt is made to establish a relation between the dielectric constant of a solvent and the strength of an acid or base [43]. As a criterion, for estimating the strength of an acid or base, the authors used the slope of the characteristic curve for these compounds in various solvents. They showed that the strength of an acid or base decreased with decreasing dielectric constant of the solvent, in agreement with conclusions previously arrived at by N. A. Izmailov [38].

Figure 3 shows characteristic curves for the methylates of alkali metals in dimethylformamide. Cesium methylate is the most strongly basic, and the basic strength drops with decreasing ionic radius of the cation [44]. It should be noted, from the slope of the characteristic curves for lithium methylate in solvents of various dielectric constants, that lithium methylate is undissociated in nonpolar solvents.

In the presence of water, as in impure dimethylformamide, the following reactions occur rapidly:

$$CH_3O^- + H_2O \rightleftarrows CH_3OH + OH^-;$$

$$OH^- + H-\overset{\overset{O}{\|}}{C}-N\begin{matrix}CH_3\\CH_3\end{matrix} \rightleftarrows H-\overset{\overset{O}{\|}}{C}-O^-$$

$$+ HN(CH_3)_2,$$

and this makes it difficult to determine the equivalent point precisely. For example, salicylic and other acids [45] show breaks in their titration curves at the equivalent points in pure dimethylformamide, but these are not apparent with unpurified solvent.

A medium often used for high-frequency titration is a mixture of benzene and a neutral or basic solvent. In a medium of benzene mixed with methanol [46], dibasic acids, whose carboxyl groups are in the cis-position and separated by one or two carbon atoms, give titration curves with sodium methylate showing two breaks; malonic and acetic acid can be determined separately in mixtures; and the anhydrides of dibasic acids also titrate with two breaks. Fatty acids in drying oils can be determined in the same medium by titration with alcoholic alkali [47]. Acids of medium strength can be determined in a 9 : 1 benzene : methanol mixture, using a solution of sodium methylate in the same solvent [48].

A number of substituted monobasic phenols have been titrated with sodium methylate in a medium consisting of benzene, methanol, and ethylenediamine [12]. Phenol, o-, p-, and m-cresols, and α- and β-naphthols can be titrated with potassium methylate in the same medium, or in a benzene-ethanol mixture.

Curves for dibasic phenols (catechol, hydroquinone, and resorcinol) show two breaks in accordance with stoichiometric calculations, whereas potentiometric and indicator methods cannot be used for the titration of these compounds [49]. Pyrogallol and phloroglucinol show three breaks in their titration curves, with good agreement between the calculated and observed points. Naphthols and cresols can be determined separately in water, in spite of the similarity of their dissociation constants in water.

There have been a number of papers on the use of various solvents and titrants [37, 48, 50, 51]. It has been found that a solution of tetrabutylammonium hydroxide in isopropanol is a better titrant than a solution of potassium hydroxide in the same solvent for the titration of weak acids in methyl isobutyl ketone, dimethylformamide, and 1 : 1 or 4 : 1 mixtures of benzene with methanol. For example, titration of a mixture of maleic and fumaric acid gives

four breaks in the curve, corresponding to stoichiometric calculations with a precision of 5% [48]. In a 4 : 1 mixture of benzene and methanol, tetrabutylammonium hydroxide has been used to titrate citric, phosphoric, and a mixture of toluenesulfonic and fumaric acids; three well defined breaks were observed in each case [50].

The investigation of pyridine as a medium for the high-frequency titration of weak and moderately strong acids has been described [51]. If alcoholic potash is used as a titrant, tartaric acid titrates as a dibasic acid. The second hydrogen ion of succinic acid and the third of citric acid do not titrate completely. Titration becomes impossible in the presence of traces of water.

A complex solvent consisting of diethylamine, diethylformamide, pyridine, and thymol has been used for titrating phenols [37]. The titrant was a solution of potassium methylate in a mixture of benzene, methanol, and pyridine. The best results were obtained with carboxylic acids of medium strength and with monobasic phenols. Precise determination of the end point in the titration of dibasic phenols was complicated by precipitate formation. Alcoholic groups, except in glycols, could not be titrated. A technique was developed for titrating carboxylic acids and phenols in mineral oils and in high-boiling fractions of shale oils.

It is well known that the best differentiating solvents for bases, acids, and their salts are ketones, particularly acetone [38] and methyl ethyl ketone [52]. The above described back titration method can be used with advantage, in a mixture of 65% acetone with water, for the determination of phenols, cresols [53], and xylenol isomers [54] in raw materials and intermediates for high polymer production. The excess alkali is titrated first, and then the o-, p-, and m-cresols and phenol. With a mixture of xylenols, the excess alkali is titrated first, and then the 1,3,5-, 1,2,4-, and 1,2,5-xylenols.

An acetone-water medium can be used for the separate analysis of o-, p-, and m-chlorophenols, but only their sum is determined when they are present together; the titrant is a solution of caustic soda in acetone-water [55]. Glacial acetic acid is the best investigated and most often used medium for the potentiometric and high-frequency titrations of organic bases [56]. The titration of bases in various solvents has been studied [57]. Pure acetic acid has been used for the titration of 16 bases with pK_{H_2O} varying from 0.98 to 10.72. The slopes of the curves and the titration end points served as measures of the basic strengths. The results agreed with data obtained by the potentiometric method [58].

The same medium has been used for oxidation-reduction titrations, such as the oxidation of dihydrobenzoquinone and benzohydrophenazine with potassium bichromate [59]. The shape of the titration curve indicates that the oxidation passes through an intermediate stage, showing increased electrical conductivity. Titration in the same medium, with a solution of perchloric acid in acetic acid, was used for determining the components of binary mixtures of aniline derivatives: p-toluidine + p-nitroaniline; p-bromoaniline + p-nitroaniline; p-toluidine + p-aminobenzoic acid; etc. [6]. Separate determinations were found to be possible for related compounds whose molecular weights differed by 30-50 units. Potentiometric and conductimetric methods could not be used for these determinations.

It is interesting to note that addition of formic acid to acetic acid, to increase the acidity, improves the conditions for titration of bases of medium strength. On the other hand, reduction of the acidity, by addition of dioxane, increase the definition of the end points in the titration of weak bases and makes their separate determination possible [58]. For example, with a mixture of acetic acid and dioxane, it was possible to determine the components of the following mixtures: 7,8-benzoquinoline and anthranilic acid; quinaldine and o-chloroaniline; triethanolamine, pyridine, and others.

Other papers have appeared on the following subjects: the titration of organic bases in acetic acid [61-63]; the titration of pharmaceutical products of a basic character in this medium [64-66] and of amino acids in a mixture of methanol and acetic acid [67]; salts of organic acids as bases in acetic acid and in a mixture of benzene with methanol [68]; other data on the analysis of organic compounds by the high-frequency method [69-73].

For further progress in the use of the high-frequency method it will be necessary to carry out more intensive research on the theory of nonaqueous solutions, and also to equip our institutes and laboratories with high-frequency titrometers* made in this country.

*The quantity production of high-frequency instruments will begin after the development of experimental samples of high-frequency titrometers types VU-1A [55, 74] and VU-2A [74-75] in the Central Design Office for Analytical Instrument Construction of the Academy of Sciences of the USSR.

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All abbreviations of periodicals in the above bibliography are letter-by-letter transliterations of the abbreviations as given in the original Russian journal. *Some or all of this periodical literature may well be available in English translation.* A complete list of the cover-to-cover English translations appears at the back of this issue.
