

NON-AQUEOUS POTENTIOMETRIC TITRATIONS OF WEAK ACIDS

by

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CHAPTER I

INTRODUCTION

"Fundamental studies concerning the nature of titration reactions in non-aqueous solvents represent a new frontier in chemistry where most of the important progress has been made since about 1957." (1) The majority of non-aqueous titrations involve neutralizations of organic acids or bases and the direct determination of acidic or basic functional groups. In addition to their importance in organic analysis, non-aqueous acid-base titrations are used extensively in pharmaceutical analysis.

The most important advantage offered by acid-base titrations in non-aqueous media is that a much larger number of acids and bases can be titrated in non-aqueous solvents than in aqueous solution. For example, a weak acid with a pK_a of 9 or greater cannot be determined accurately in water because of the competition between the weak acid and the solvent, water, for the strong base titrant. The weak acid can, however, be titrated in ethylenediamine which is considerably more basic than water and thus will not react with the strong base titrant. Other advantages include: 1) the titration can be easily carried out and requires no special, expensive apparatus or special training, 2) the titrations yield very accurate results, often more precise than those obtained from aqueous titrations, and 3) the titrations can often save tedious and laborious procedures saving much

time, especially in routine work. (2)

Non-aqueous solvents can be classified by properties into four principle groups: 1) aprotic, 2) amphiprotic, 3) protogenic, and 4) protophilic solvents (2). Aprotic solvents contain no readily ionizable proton and possess a low dielectric constant. Typical examples are acetone, acetonitrile, benzene, and chlorinated hydrocarbons. Amphiprotic solvents possess neither strongly acidic nor strongly basic properties. They tend to have high dielectric constants and their autoprotolysis constants are usually less than that of water. Alcohols belong to this group. Protophobic solvents have a slight amphoteric character, but they possess predominantly acidic properties. They tend to have high dielectric constants and their autoprotolysis constants are usually greater than that of water. Typical examples of this group would be acetic acid and formic acid. Protophilic solvents also possess a slight amphoteric character, but are predominantly basic in their properties. They tend to have high dielectric constants with their autoprotolysis constants usually less than that of water. Typical examples of this class are ethylenediamine and dimethylformamide.

The choice of a solvent for the particular titration is very critical. Properties of solvents which are desirable are these:

- 1) the solvent should dissolve the substance to be titrated, 2) should not introduce interfering side reactions with either the substance to be titrated or the titrant, 3) should permit a large change in the solvated proton concentration near the equivalence point, 4) should be easily purified, and 5) preferably should be inexpensive. In addition

if the solvent is to be used for a differentiating titration it should be neither strongly acidic nor strongly basic to avoid "leveling" effects.

The titrants most often used for weak acids are the quaternary tetraalkyl ammonium hydroxides. These have certain advantages over the alkali metal hydroxides and alkoxides; namely, the salts of quaternary ammonium hydroxides are generally soluble and there is no alkali error introduced when using the glass indicating electrode. To insure that the titrant solvent does not interfere with the principle reaction, the concentration of the titrant solution is usually kept high relative to the concentration of the substance titrated.

To perform the titration quantitatively one must be able to detect the equivalence point (or more practically the end point). Historically this was first done by means of acid-base indicators. In non-aqueous solutions, however, indicators often do not reveal the equivalence point. It has been necessary then to develop other means for end point detection. There are a great many instrumental techniques which have been developed, among these are potentiometric, conductometric, coulometric, thermometric, high-frequency oscillometric (conductance or capacitance), cryoscopic, and photometric titrations. Of the various methods developed, potentiometric and conductometric are perhaps the two most commonly used. Since this work is involved with potentiometric methods, only these will be discussed.

In a typical non-aqueous potentiometric acid-base titration, one might use the common glass-calomel electrode couple. As in aqueous

solution, in most non-aqueous solvents the glass electrode appears to respond to the difference between the activity of the solvated proton in the solution inside the glass membrane and the activity of the solvated proton in the solution on the outside. Unfortunately, a quantitative relationship which would relate the electromotive force (e.m.f.) of the electrochemical cell to the constituent concentration is not clear cut. In the first place, ion activities in one solvent cannot be simply related to ion activities in another solvent. In addition, when the e.m.f. of the above cell is measured, one includes a sizable, unknown, liquid junction potential between the aqueous calomel electrode and the non-aqueous solution. For these reasons the potential break (when plotted as e.m.f. versus volume of titrant added) is used empirically to determine the end point.

Literature Survey

Since this thesis is concerned only with the titration of weak acids the discussion will be limited primarily to weakly acidic organic compounds.

Background of Methods

One of the earliest papers describing the use of non-aqueous solvents was that of Folin and Wentworth (3) who titrated the higher fatty acids in aprotic solvents. With regard to the concepts of neutralization titrations current at that time, this was a revolutionary choice! They were the first to prove that although benzene solutions of fatty acids were not ionized, (based on electrical conductivity) these solutions could still be titrated with a strong

base. These early results were overlooked and later investigators (4,5,6,7,8,9) often used alcohols (amphiprotic solvents) for titration of weak acids. As late as 1948, Moss, Elliott, and Hall (10) used the very basic solvent ethylenediamine (EDA) for the titration of very weak acids found in resins, even though the Brønsted-Lowry theory (11,12), the source of the idea, had been known for over twenty years. This work initiated the selection of protophilic solvents as suitable for the determination of weak acids.

Moss, Elliott, and Hall (10) found that a mixture of phenols and carboxylic acids when titrated with sodium 2-aminoethoxide in EDA gave analogous results to those obtained in water with a mixture of carboxylic acids and mineral acids. The indicator system consisted of an antimony reference electrode sealed in the buret tip. Katz and Glenn (13) extended their work by using a strip-chart recorder to obtain the first-derivative titration curve.

Fritz and Lisicki (14) compared the feasibility of titration in a principally aprotic solvent system, benzene-methanol (3:1), to that of a protophilic solvent, n-butylamine. Although carboxylic acids, acid chlorides, acid anhydrides, enols, amine salts, and some mercaptans and imides could be titrated in either, using thymol blue indicator, very weakly acidic compounds such as phenol could only be titrated potentiometrically in n-butylamine. They pointed out that with n-butylamine as solvent the antimony electrode appeared to serve as the indicating electrode, while the glass electrode acted as the reference electrode.

Fritz and Keen (15) utilized visual indicators to determine phenols in two protophilic solvents, EDA and dimethylformamide (DMF). They found that they could determine phenols with electron withdrawing substituents in DMF, but phenol and alkyl-substituted phenols caused the azo violet end point color to change gradually and prematurely. They then showed that several phenols could not be titrated in EDA using o-nitroaniline as the indicator.

Harlow, Noble, and Wyld (16,17) then developed an electrode couple that could be used for titrating very weak acids in a very basic solvent, EDA, with an alkali metal hydroxide, potassium hydroxide. The electrode couple consisted of an anodically polarized platinum wire dipping into the solution being titrated and an unpolarized platinum wire in the titrant stream serving as a reference electrode. The potential ranges were as much as three times those obtained with standard antimony-calomel couples. The curves were more readily compared when a titrant free of the alkali metal effect, tetrabutylammonium hydroxide (TBAH), was used.

Cundiff and Markunas (18) were the first to employ a TBAH titrant in a benzene-methanol (10:1) solution. They also modified the calomel electrode by replacing the saturated aqueous solution of potassium chloride with a saturated potassium chloride solution in methanol. Good results were obtained when acids of different strengths such as the weak acids, succinimide, salicylaldehyde, acetyl acetone, α -toluenethiol, and phenol.

Several workers noticed that the TBAH titrant seemingly contained some impurities which led to high results (19,20). Marple

and Fritz (21) undertook an investigation into the sources of these impurities in TBAH prepared by the silver oxide method. The three most likely sources of impurities present in the titrant prepared in this manner are 1) tertiary amines (from Hofmann elimination (22)), 2) carbonates, and 3) anionic silver complexes. These three impurities could be removed by means of ion exchange; amine impurities could be extracted with benzene; and the amount of anionic silver complex reduced by preparing TBAH in methanol containing 25—50 % water.

Cundiff and Markunas (23) later developed a method that eliminated these impurities. They prepared essentially carbonate free silver oxide, limited the exposure of the titrant to atmospheric carbon dioxide, and by carrying out of the reaction at -10° C cut down on the decomposition of the TBAH and lowered the solubility of anionic silver complex.

Fritz and Marple (20) investigated the use of tert-butyl alcohol for the titration of weakly acidic compounds and for differential titrations. Tetrabutylammonium hydroxide was used as the titrant in an isopropanol-water-benzene solvent. They obtained titration curves that were more sharply defined than those obtained when acetone, acetonitrile, or pyridine were used as solvents. They found that the titration in pyridine gave results which were 2-4 % too high because of carbonate impurity (24).

Stamey and Christian (25), using a modification of Cundiff and Markunas' procedure (23), developed a titrimetric method for determining

hydroxamic acids in DMF, acetone, methyl ethyl ketone, isopropanol, pyridine, and tert-butyl alcohol. The largest relative end point break and the fastest response were obtained in DMF with platinum indicator and buret titrant reference electrodes.

Heumann (26) developed in 1961, a quaternary ammonium alkoxide, 0.3N tetrabutylammonium ethoxide solution in ethanol-benzene (1:10), which proved to be a more strongly basic titrant than the alkali metal alkoxides and the hydroxides of quaternary ammonium salts. Breaks of approximately twice the magnitude of those of the alkali metal alkoxides and the quaternary ammonium hydroxides were obtained. The greatest potential rise was observed in EDA medium with an anodized platinum indicator-buret reference couple.

Lee (27) developed a microtitration procedure for dibenzoylmethane and other weak acids in pyridine and EDA. The titrant used was a modification of the very strong titrant the Heumann (26) had developed. Lee investigated various polarized electrodes among which anodized platinum in conjunction with cathodized antimony microelectrodes responded best. Pyridine in general was better than EDA because it did not absorb carbon dioxide as readily, but extremely weak acids (2,3 butanedione and dimethylglyoxime) gave larger potential breaks in EDA than in pyridine.

Buell (28) developed a differential titration for acids of different strengths found in petroleum using TBAH and a pyridine-benzene solvent (1:1). This was developed primarily for those compounds which would not titrate in alcoholic systems, with pK_a 10 to 13. The weakly acidic compounds in petroleum are believed

to be heterocyclic compounds. He reported the titration of carbazole, but gave no information as to the accuracy attainable.

Belcher et al. (24) developed submicro methods (0.3 ml. solvent) for the determination of acidic hydroxyl groups in various solvents using TBAH in benzene-methanol as the titrant. With compounds of pK_a greater than 8, he found that no indicator tried gave satisfactory results and that the glass-silver electrode gave unsatisfactory curves. Upon trying a glass-platinum electrode pair, he noticed a 2 to 3 fold increase in sensitivity and was able to titrate the weaker acids (pK_a 8 to 10). The solvents tested, showed the following order of decreasing potential break; pyridine $>$ acetonitrile \approx DMF $>$ acetone $>$ methyl ethyl ketone.

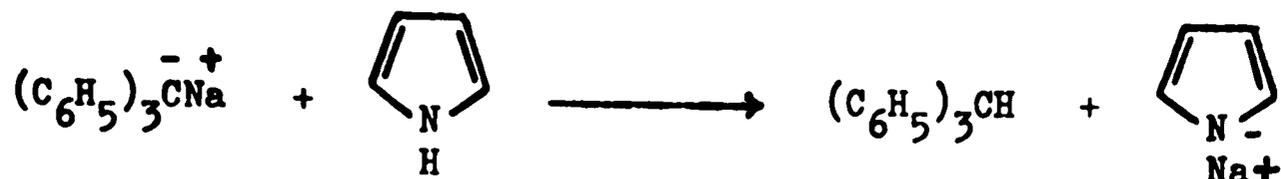
Jewel and Hartung (29) while trying to identify the nitrogen compounds in gas oil, adopted a modified method of Moss, Elliott, and Hall (10). Using anhydrous sodium aminoethoxide in EDA as titrant, they found that several representative nitrogen compounds containing an active hydrogen were sufficiently acidic to yield sharp equivalence points. They were able to determine the 2-,4-, 5-,7-, 8- hydroxyquinolines, indole, and carbazole, but no curves nor quantitative data on the accuracy or precision possible were given.

Background of Problem

Pyrrole is a very weak acid with a pK_a of about 16.5 (30). This makes it a much weaker acid than glucose or hydrogen peroxide and makes it comparable to methanol (pK_a 15.5) in acidic strength. Albert (31) states that carbazole and indole have acidic strengths

of about the same order as that of pyrrole.

Corwin and Ellingston (32) were the first to successfully titrate pyrrole type compounds. To accomplish this, they used the very powerful base, sodium triphenylmethane in a 1:1 ether-toluene solution. The reaction is:



The ether-toluene solution of the titrant has a deep blood red color and since all other products are colorless, the titrant serves as its own indicator. The success of this method depends upon the very careful purification of the solvents used and the complete exclusion of moisture, carbon dioxide, and oxygen. Because of these rather stringent conditions the apparatus used is very bulky and complicated.

W. Huber (33) converted nitro, azo, and pyrrole derivatives to amines by hydrogenation in acetic acid followed by titration with perchloric acid. Using tributylmethylammonium hydroxide, he was also able to determine benzopyrroles selectively by direct potentiometric titration in pyridine.

Zonova and Matveeva (34) in determining phenols in tar studied the determination of individual compounds by potentiometric titration. They used isobutyltrimethylammonium hydroxide in a methanol-pyridine (1:48) solution in conjunction with a glass-calomel electrode couple. The titration curves they obtained showed a sharp inflection with phenol, thymol, 1- and 2-naphthols, catechol, and carbazole, as well as the mixture 1-naphthol and catechol (1:1). Hydroquinone, resorcinol, pyrrole and its derivatives failed to give sharp potential changes.

Statement of the Problem

Since little work has been done on the use of TBAH for titration of acids with pK_a 's from 12 to 16, the problem then was to investigate its use in both protophilic and aprotic solvents.

Furthermore, an investigation of the optimization of the electrode system by comparing the advantages of various glass-modified reference electrodes with those of the platinum-platinum electrode developed by Harlow et al. (16) was undertaken.

Finally the comparison of TBAH with the more recently developed tetrabutylammonium ethoxide (26) was made with both platinum-platinum couples and combination glass electrode.

CHAPTER II

EXPERIMENTAL

Purification of Solvents

Since water is the main impurity of concern in non-aqueous solvents, the purification procedures are concerned with the removal of even traces of water. Often solid desiccants are used for preliminary desiccation followed by common or fractional distillation to remove the last traces. When distilling anhydrous solvents, it is imperative not to permit entry of moisture into the distillation apparatus. This can be done by using an all glass distilling apparatus with the outlet of the adapter protected by a tube containing a solid desiccant. During the distillation of a solvent sensitive to carbon dioxide, this tube must also be filled with a desiccant capable of absorbing carbon dioxide, i.e. Ascarite.

Benzene

Benzene (Thiophene free, Mallinckrodt Analytical Reagent Grade) was allowed to be in contact with a small quantity of cleaned metallic sodium for several days, with intermittent shaking. The benzene was then distilled in an apparatus protected from atmospheric moisture and carbon dioxide by a drying tube containing Ascarite (20-30 mesh) and Dehydrite. The first 50 ml. were rejected and the fraction from 76-76.4° C (676 torr) was collected. After collection, the benzene

as well as all other solvents hereafter mentioned was transferred to an oven dried glass bottle with a 100-ml. pipet, hermetically sealed, and stored at 10° C in a refrigerator until used. Before use the bottle was brought out of the refrigerator and allowed to come to room temperature.

Ethanol

Ethanol was dried according to the procedure of Vogel (35). One liter of absolute ethanol (commercial grade) was allowed to react with 7g. of metallic sodium in a reflux setup. After the reaction subsided, ethyl phthalate (27.5g.) was added and the mixture refluxed for 2 hours. The water of the condensor was let out and the distillation begun. After rejecting the forerun (30 ml.), the fraction boiling from $75-75.4^{\circ}$ C (677 torr) was collected, transferred, and stored as mentioned above.

Ethylenediamine

Ethylenediamine was dried by the recommendations of Kucharsky and Safarik (2). The ethylenediamine (Baker Analyzed Reagent) was shaken with flake potassium hydroxide for 4 days on a mechanical shaker, then pipetted into the distillation apparatus described in the benzene purification, and distilled over excess metallic sodium with the fraction from $112.6-113^{\circ}$ C (679 torr) being collected. In some of the later experiments anhydrous ethylenediamine "for non-aqueous titrations" prepared by G. F. Smith Co. was used without further purification.

Pyridine

Anhydrous pyridine was prepared by shaking the commercial

product (Mallinckrodt, Analytical Reagent Grade) with flake potassium hydroxide. The mixture was allowed to stand 10 days with intermittent shaking and finally decanted into the previously mentioned distillation apparatus and distilled over barium oxide. The middle fraction, 109.6–110.2° C (683 torr) was collected and stored as above. In later experiments Karl Fischer Reagent Grade pyridine distilled by Eastman Distillation Products was used without further purification.

Isopropanol

Commercially available isopropanol was dehydrated by shaking with 10 per cent of its weight of flake sodium hydroxide, separating the alcohol layer, shaking with a fresh portion of sodium hydroxide, and finally fractionally distilling using a 30 cm. Vigreux column in conjunction with the previously described distillation setup. The first 20 ml. was rejected and the middle fraction, 78.5–79° C at 680 torr, collected.

Tertiary Butanol

Tertiary Butanol (commercial grade) was dried according to the method of Huber (36). That is, fractionally distilled (30 cm. Vigreux column) over an excess of metallic sodium. The fraction boiling from 78.5–80° C (676 torr) was collected after rejecting the first 50 ml. of distillate. After distillation, the tert-butanol was immediately pipetted into the solvent reservoir (protected from atmospheric moisture and carbon dioxide), and the bottom covered with molecular sieves (Linde, 1/16").

Preparation of Compounds

Tetramethylammonium Hydroxide

Tetramethylammonium hydroxide (TMAH) was prepared by the procedure of Harlow and Wyld (38). A slight excess of TMAH (K & K Laboratories) was added to 100 ml. of a 0.2N KOH isopropanol solution. The mixture was shaken vigorously over a period of 15 minutes and then the precipitated KCl was allowed to settle. The clear supernatant was then withdrawn with a 100 ml. pipet to the titrant reservoir which was then fitted with a drying tube containing Ascarite and Deydrite.

Tetrabutylammonium Hydroxide

The tetrabutylammonium hydroxide (TBAH) was prepared by two methods—the silver oxide method (2), and a modified silver oxide method (23).

The silver oxide method consisted of dissolving 10g. of tetrabutylammonium iodide (K & K Labs.) in 25 ml. of anhydrous ethanol (see p. 13). Five grams of silver oxide (commercial grade) was added and the mixture stirred with a teflon magnetic stirring bar for one hour. Approximately 1 ml. of the suspension was withdrawn, centrifuged and tested for iodide. Since it gave a positive test, an additional gram of silver oxide was added and the reaction allowed to proceed another hour. The suspension was then filtered through a fine porosity fritted filter, washed with 50 ml. of cold benzene, and then withdrawn with a 25 ml. pipet to a 250 ml. volumetric flask. It was then diluted to the mark with anhydrous benzene (p. 12) and pure

nitrogen was bubbled through the solution for 5 minutes to purge the carbon dioxide absorbed during filtration. The titrant was then transferred to a 250 ml. Erlenmeyer flask, tightly stoppered, and stored in a desiccator.

Due to the unreliable results obtained with the TBAH as prepared above, a modification of the improved method of Cundiff and Markunas (23) was tried next.

Carbonate free silver oxide was prepared by dissolving 7.5 g. of AgNO_3 (A.C.S. Reagent Grade) in 13 ml. of carbonate free water and adding 14 ml. of a 4 N Carbonate free NaOH solution. The silver oxide immediately precipitated and was filtered under nitrogen through a medium porosity sintered glass funnel and washed with 200 ml. of boiling water and 75 ml. of ethanol. Ten grams of tetrabutylammonium bromide (K and K Labs.) were dissolved in 25 ml. of anhydrous ethanol in a 250 ml. round bottom flask and chilled in a -10°C salt-ice bath. The previously prepared, ethanol moist, silver oxide was added, the flask flushed with nitrogen, tightly stoppered, placed in the salt-ice bath, and allowed to react for 1 hour shaking every 5 minutes. After 1 hour 225 ml. of benzene (which had been purged with nitrogen) was pipetted into the flask, the flask reflashed with nitrogen, restoppered, shook vigorously, and then replaced in the salt-ice bath for 15 minutes. The suspension was then filtered under a nitrogen atmosphere through a fine porosity sintered glass funnel, the filtrate transferred via a 100 ml. pipet to a 250 ml. volumetric flask, and allowed to warm to room temperature. Two layers formed, probably because of the substitution of ethanol

for methanol; therefore, it was necessary to add, in addition to 10 ml. of benzene, 15 ml. of ethanol to obtain a clear one-phase solution. This subsequent dilution decreased the normality from the expected 0.1 N to 0.0788 N.

Sodium Ethoxide

Sodium ethoxide was prepared several times. It was found to rapidly turn a brown color upon standing; therefore, it was prepared and used immediately in the preparation of tetrabutylammonium ethoxide.

The preparation of 4 N sodium ethoxide was carried out in a reflux system fitted with a drying tube to protect the solution both from moisture and carbon dioxide. Seven grams of freshly cut sodium metal was washed clean of any oxide coating with ethanol and then added to 120 ml. of anhydrous ethanol in a round bottom flask. A heated-magnetic stirrer was used to stir the reaction mixture. In order to drive the reaction to completion the system was heated with stirring until all of the sodium metal had reacted. Immediately upon cooling, the sodium ethoxide was pipetted into the reaction flask used in preparing tetrabutylammonium ethoxide.

Tetrabutylammonium Ethoxide

Several attempts were made to prepare tetrabutylammonium ethoxide (TBAE) by a modification of the method of Heumann (26). The modification consisted of substitution of the iodide salt for the bromide salt and ethanol for methanol. Probably due to solubility differences, the precipitation of the sodium iodide

did not occur. The final use of the bromide salt was successful.

A 0.33 M solution of tetrabutylammonium bromide (TBAB) in 100 ml. of benzene was made by dissolving the appropriate amount (10.64 g.) of TBAB. Upon the addition of 10 ml. of the previously prepared sodium ethoxide, sodium bromide immediately precipitated. The precipitate formed was very gelatinous and required setting overnight to settle out. The supernatant was pipetted into the titrant reservoir and protected from atmospheric moisture and carbon dioxide.

Pyrrole and Other Acids

Pyrrole oxidizes readily in air, first to a yellow color, then brown, and finally forms a black resin (31). Since the pyrrole (K and K Labs.), as received, was dark brown in color it was purified by vacuum distillation (8 mm) through a short path distillation setup. It was stored in the collector after being purged thoroughly with nitrogen. Carbazole (K and K Labs.) and benzoic acid (A.C.S. Grade) were dried overnight in a 110° C oven and stored when not in use in a desiccator. Upon attempting to dry indole in the same manner it formed a green colored compound, probably due to air oxidation; therefore, indole as well as phenol (Mallinckrodt, Analytical Reagent) and 2-naphthol (Fischer Certified Reagent Grade) were used as obtained.

Apparatus and Procedure

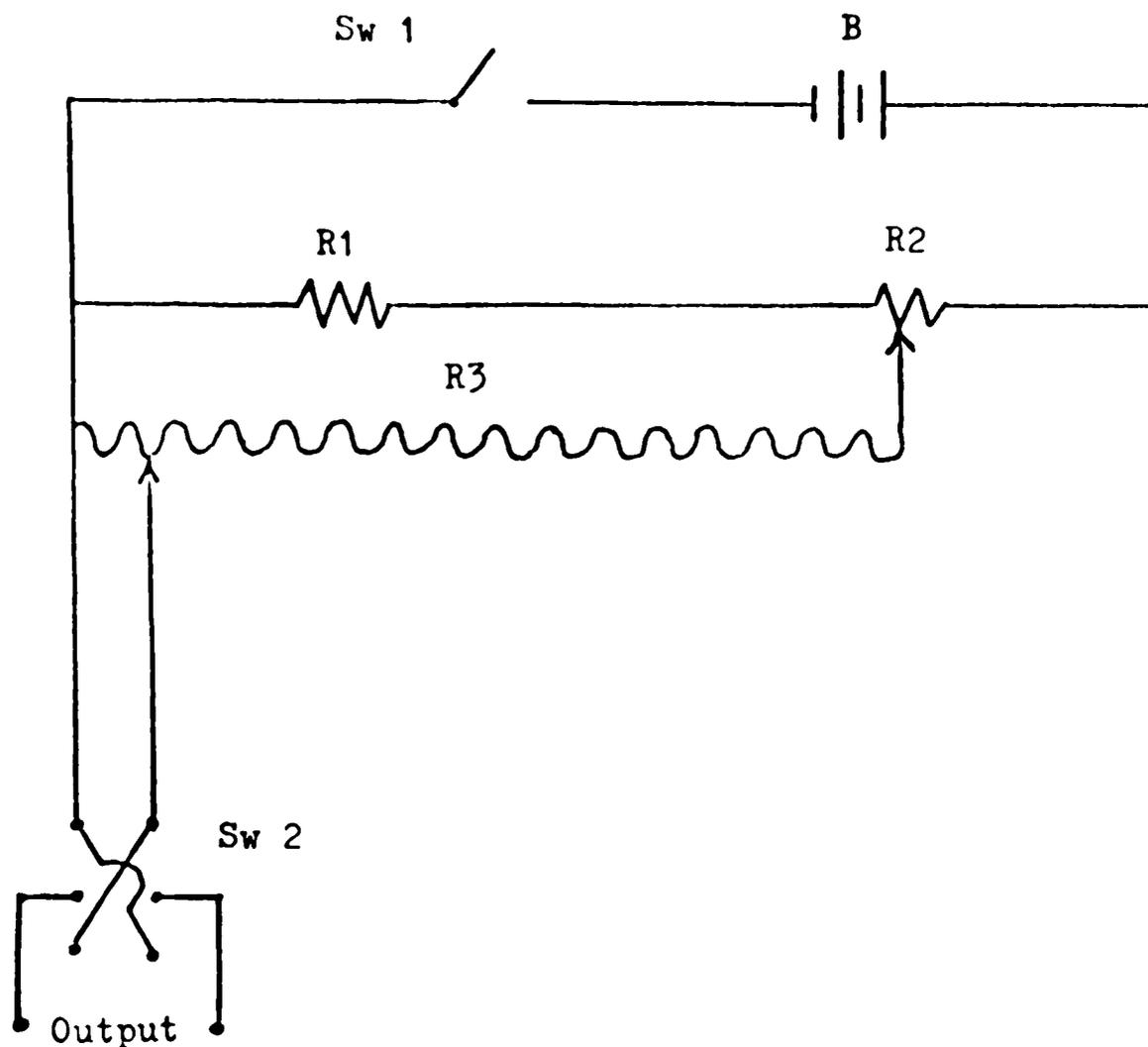
Electrometric System

The apparatus consisted of a Sargent Combination Electrode (S-30072-15) used in conjunction with an Orion Research Ionalyzer

digital pH meter (Model 801) and a Bausch and Lomb VOM 7 recorder. For maintaining the recorder on scale, a bucking potentiometer (see Fig. 1) with a range of ± 1000 millivolts was inserted into the reference electrode lead to the pH meter. An attenuator was also inserted between the pH meter and the recorder to give attenuations of approximately 1, 1/2, 1/5, and 1/10. A block diagram of the electrometric system is given in Figure 2.

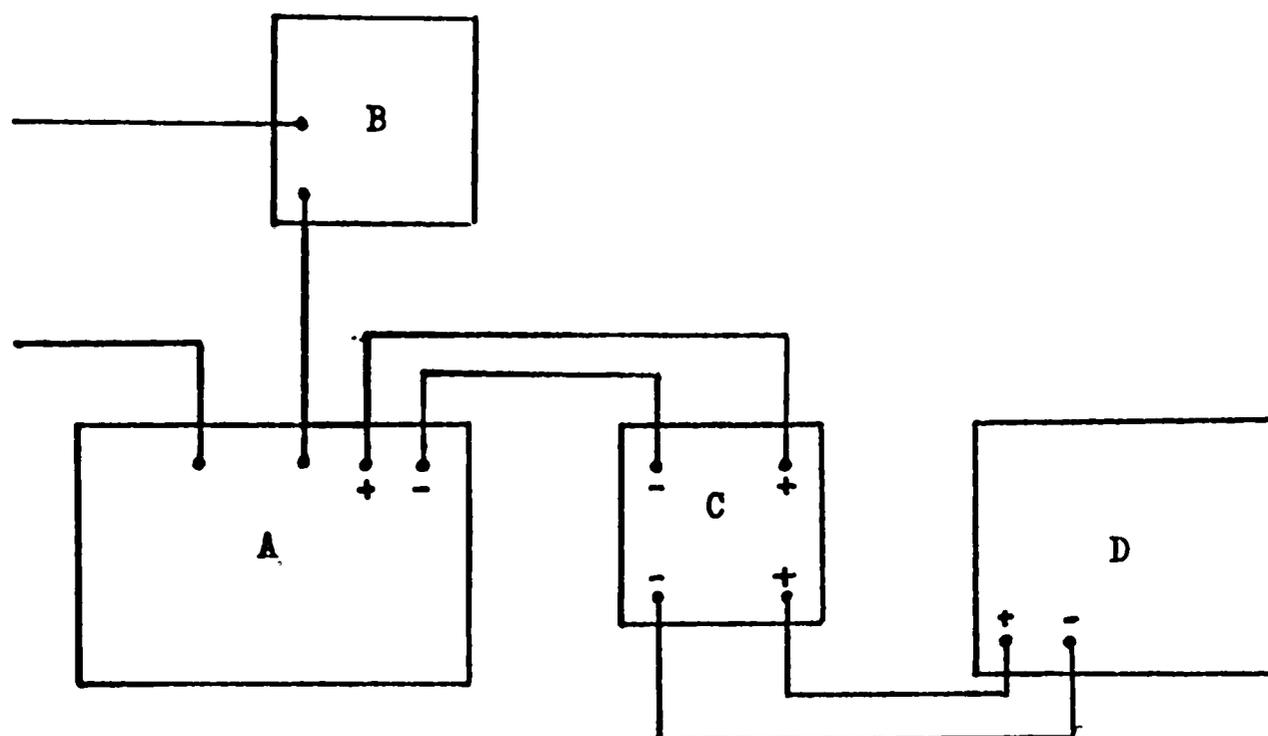
Titration System

A 180 ml. electrolytic beaker was fitted with a drilled no. 10 rubber stopper as electrode holder to protect the contents from carbon dioxide and water and to protect the operator from toxic or corrosive fumes. Five holes were drilled in the stopper for admitting the combination electrode (or platinum indicating electrode), the solvent delivery tube, the buret tip, the nitrogen inlet (with platinum reference electrode inserted in a T tube when using platinum-platinum couple), and a vent tube (see Fig. 3). The buret was a 10 ml. Micro "A" buret (Kimax 17115-F) fitted with a three-way stopcock with teflon plug and graduated in 0.02 ml. divisions. A 100 ml. reservoir was attached to the buret inlet and fitted with a drying tube. The titration solvent was delivered from a single neck 1-l. pyrex bottle with a 29/42 standard taper joint through a glass delivery system containing a 12/5 ball joint and a stopcock, as shown in Figure 4. The outlet tube on the solvent reservoir was fitted with a drying tube containing Ascarite and Deyhdrite. The joints and stopcock of the solvent delivery



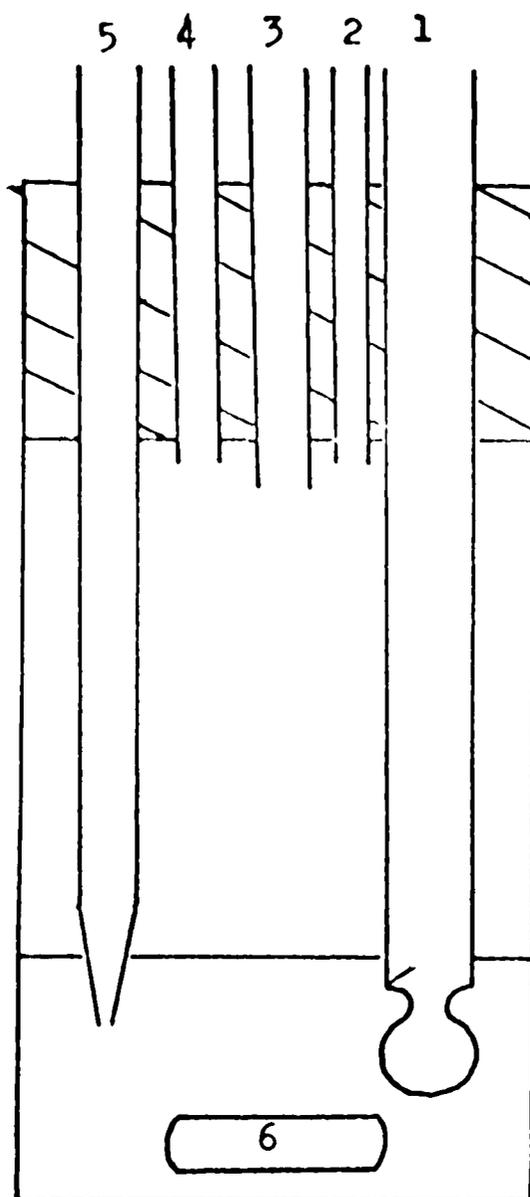
- Sw 1. Single throw switch
 B. 1.4 volt Mallory (Dura Cell) mercury dry cell
 R1. 220,000 ohm fixed current limiting resistor
 R2. 50,000 (Type J) potentiometer
 R3. 100 ohm Precision Multipot potentiometer,
 Ford Engineering Co.
 Sw 2. Double pole, double throw switch

Figure 1. Bucking Potentiometer



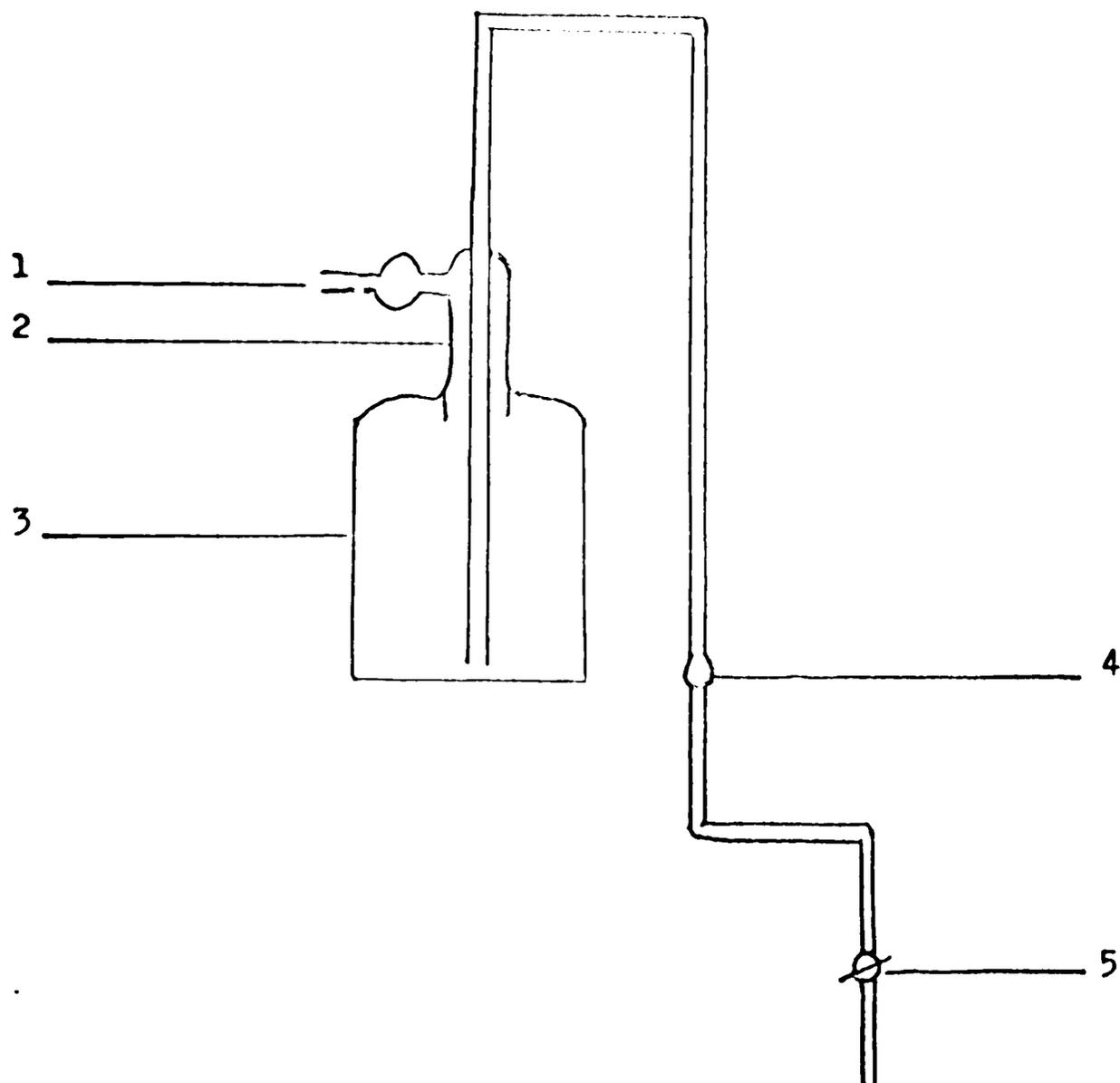
- A. pH meter
- B. ± 1000 mV. bucking potentiometer
- C. Attenuator
- D. Recorder

Figure 2. Arrangement of Electrometric System



1. Combination electrode
2. Nitrogen inlet
3. Solvent inlet
4. Nitrogen outlet
5. Buret tip
6. Magnetic stirring bar

Figure 3. Titration vessel



1. Drying tube filled with Ascarite and Deydrite
2. 29/42 $\bar{\text{S}}$ glass joint
3. 1-l. Pyrex bottle
4. $\bar{\text{S}}$ 12/5 ball joint
5. Stopcock

Figure 4. Solvent Delivery System

system were greased lightly with Dow Corning High Vacuum Silicone Grease. A magnetic stirrer supported the titration vessel and drove a teflon coated magnetic stirring bar during titration. The tank nitrogen used to purge the titration vessel after closure from the atmosphere was purified by passing through successive Midvalve absorption bulbs filled with Ascarite and Drierite to remove carbon dioxide and water respectively.

Procedure: Combination Electrode

A quantity of acid sample sufficient to give a titration of about 1 ml. was weighed to the nearest tenth of a milligram into the titration vessel, a 180 ml. electrolytic beaker, which already contained the stirring bar. The combination electrode was removed from the solvent, in which it was stored when not in use, and transferred to the titration vessel. Purified nitrogen was flushed through the apparatus for 1 min. at a rate of ca. 400 ml./min. and then decreased to ca. 50 ml./min. for the duration of the titration. A volume of solvent was then admitted to the system until the asbestos fiber tip of the electrode and the buret tip were just covered. The magnetic stirrer was then turned on and the speed adjusted for efficient stirring but not so high that spattering of the solution occurred. The function switch on the pH meter was then turned to the millivolt position, the recorder switch turned to the record position and the initial potential (after electrode had reached a constant value) was read on the pH meter and recorded (to the nearest millivolt) by hand on the strip chart paper. The bucking potential was then adjusted to give a reading of between 0 and -100 millivolts,

this being recorded on the chart paper as the initial potential. The titration was carried out by adding increments of 0.1 ml. until approaching the end point when 0.04 ml. and then 0.02 ml. increments were added successively. After addition of an increment, the potential was allowed to reach a constant value (less than 2 mV change in 30 seconds) and then recorded on the chart paper by hand to the nearest mV. Successive increments were added until the titration carried beyond the end point as evidence by a leveling off of the millivolt change with subsequent additions after the break. After the titration was completed the electrode surface was rinsed thoroughly with acetone, wiped off with tissue, and immediately placed back into the storage vessel containing the solvent being used. The results were plotted on graph paper as E. M. F. (mV) versus milliliters of titrant added and the smoothest curve drawn through the points. Standardization was made with dried benzoic acid (A.C.S. Grade) using the solvent in which the sample acids were titrated. A solvent blank was determined for each individual solvent. The temperature was controlled to within $\pm 3^{\circ}\text{C}$ by a room air conditioner which necessitated no corrections for temperature changes.

Three different types of electrolytes were used in the reference thallium amalgam electrode. The first one tried was simply an ethanoic solution saturated with KCl. The second one used was a 0.01 M solution of tetrabutylammonium bromide in ethanol. The third was an ethylenediamine solution saturated with LiCl.

Procedure: Polarized Platinum Electrode

The procedure followed using the platinum-platinum couple was in general the same procedure using the combination electrode. The only difference was in the treatment of the electrode. The indicator electrode was prepared by anodically polarizing the platinum wire. This was done by immersing the electrode in a 5 % aqueous H_2SO_4 solution and making it the anode with respect to a platinum wire acting as the cathode. A potential of 3 volts was applied and the electrolysis allowed to proceed 3 minutes. It is not certain exactly what occurs on the surface of the platinum during polarization, but it is thought that the surface is charged with oxygen (16). The reference electrode used was simply a bare piece of platinum wire of the same size as the indicator electrode, sealed in a T tube (which served also to introduce nitrogen), dipping into the solution being titrated. The treatment was not long lasting and therefore was repeated before each titration. After titration the electrodes were rinsed with water and then in acetone and allowed to stand in air until the next titration when they were again repolarized. After prolonged use platinum develops an insensitivity to the polarization process (16), so it was necessary to rejuvenate the electrode by letting it stand in HCl (1:1) for 3 or 4 hours every few days.

CHAPTER III

DISCUSSION AND INTERPRETATION OF RESULTS

Tetramethylammonium Hydroxide

Initial experiments were made using the polarized platinum indicating-bare platinum reference electrode couple as described by Heumann (26) and Harlow et al. (16).

The first titrant investigated was a 0.1 N solution of tetramethylammonium hydroxide (TMAH) in isopropanol. This titrant was chosen because of the advantage of ease of preparation and because the platinum couple was not subject to the alkali metal error (the titrant was about 5×10^{-3} M in potassium ion). The solvent used was purified pyridine. Although literature results using the platinum couple were reported to be good, the curves obtained as shown in Figure 5 were not smooth and contained certain anomalies. Van der Heijde (38) attributed irregular rises similar to the ones found in Figure 5 to acid-anion association and acid dimerization caused by the low dielectric constant of the solvent. Lack of reproducibility of curves was also noted. The lack of reproducibility of titration curves in non-aqueous solvents has been attributed to the fact that polar substances (acids) dissolved in a less polar solvent show a tendency to be adsorbed onto a surface having a polar character, such as the surfaces of electrodes (2). Consequently, the concentration of the substance in question on the electrode surface is different from its concentration in the bulk of

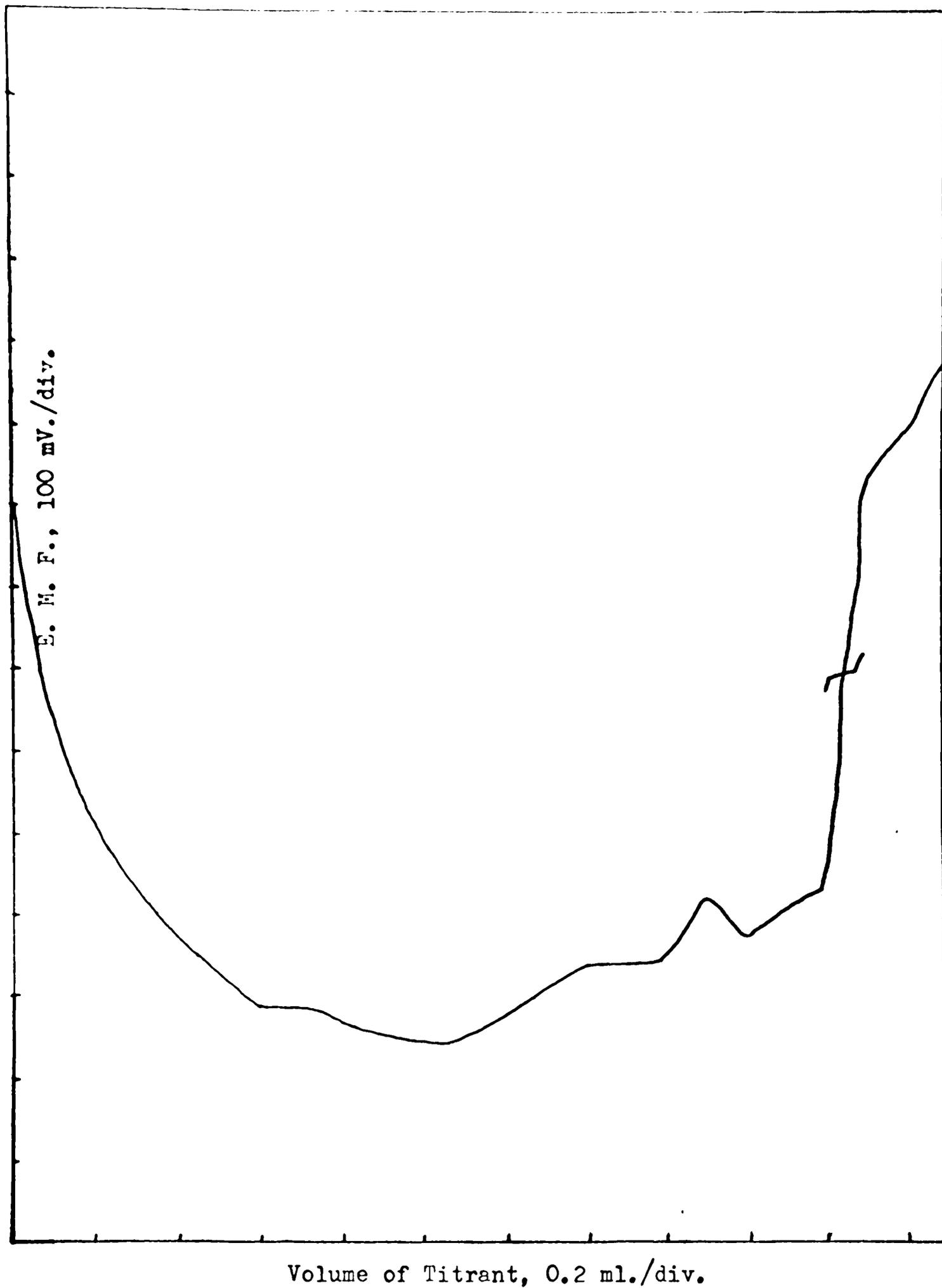


Figure 5. Titration of Benzoic Acid in Pyridine with TMAH:
Platinum electrode

the solution resulting in a delayed reaction of the electrode to the potential for the bulk of the solution. Neglecting those irregular breaks, good results were obtained with benzoic acid with two successive standardizations yielding the same normality, 0.173 N. The titration of carbazole produced no observable break; therefore, another titrant was sought.

Tetrabutylammonium Hydroxide

The next series of experiments were made with tetrabutylammonium hydroxide (TBAH) prepared by the silver oxide method. Again pyridine was used as the solvent. As with the TMAH titrant, the curves contained irregular variations and no degree of reproducibility could be obtained. Since the only thing changed was the titrant and its solvent (1:10 ethanol-benzene), the non-reproducibility was probable due to some impurity in the titrant. Titrations of carbazole again gave no detectable break.

To try to improve the electrode system the modification suggested by Lee's work (27) was tried. Lee stated that he obtained steadier and more reproducible potentials when the platinum reference electrode was also cathodically polarized in like manner to the anodic polarization of the indicating electrode. The curves obtained as shown in Figure 6, were indeed much smoother, but the potential breaks were reduced so much as to make them of little use. The curves also had no flat portion before or after the end point which makes it difficult to locate the end point with any degree of accuracy. The probable cause of these poorly defined curves was the position of the reference electrode.

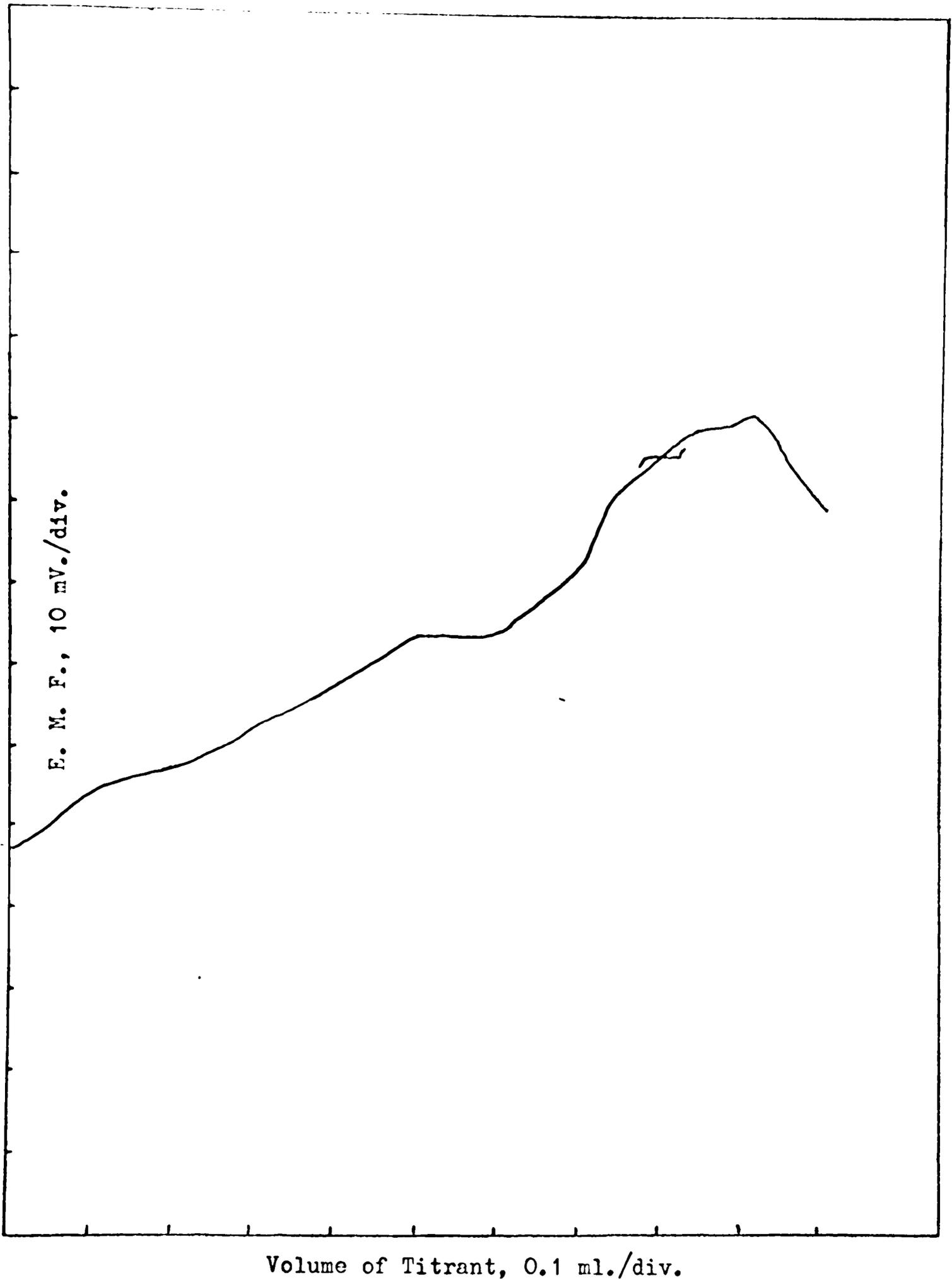


Figure 6. Titration of Benzoic Acid in Pyridine with TBAH:
Platinum electrode

Heumann (26) and Harlow et al. (16) used systems in which the reference electrode was sealed into the buret tip which was dipping into the solution. As Moss et al. (10) pointed out, this position of the reference electrode affords the advantage of continual flushing of the reference electrode thus preventing diffusion and permitting renewal of the liquid junction at the end of the buret tip (serving as a salt bridge) with each new addition of titrant.

Because of the difficulties arising with the use of the platinum-platinum couple, it was necessary to attempt to find another electrode system which would give better reproducibility and decrease or eliminate the anomalies. The first modification tried was the use of the combination glass electrode containing as reference electrolyte a saturated potassium chloride solution in ethanol. The results obtained were much better than those obtained with the platinum couples. The first solvent used was again pyridine. The break obtained with standardization against benzoic acid covered a span of about 550 mV compared to a span of about 120 mV with the platinum couple. More important, the curves were well defined with no anomalous humps (see Figure 7). The curves were fairly reproducible with the end point potentials varying only about 100 mV from the average. The standardization results were better than those using TBAH and platinum couples but they still had a rather large deviation (32 parts per thousand relative deviation). The standardization results are shown in Table I. Carbazole gave a fairly good break, but indole gave such a small break that the end point was difficult to locate with precision (see Figure 8). The summary of the results obtained with titration of weak acids are shown in Table II.

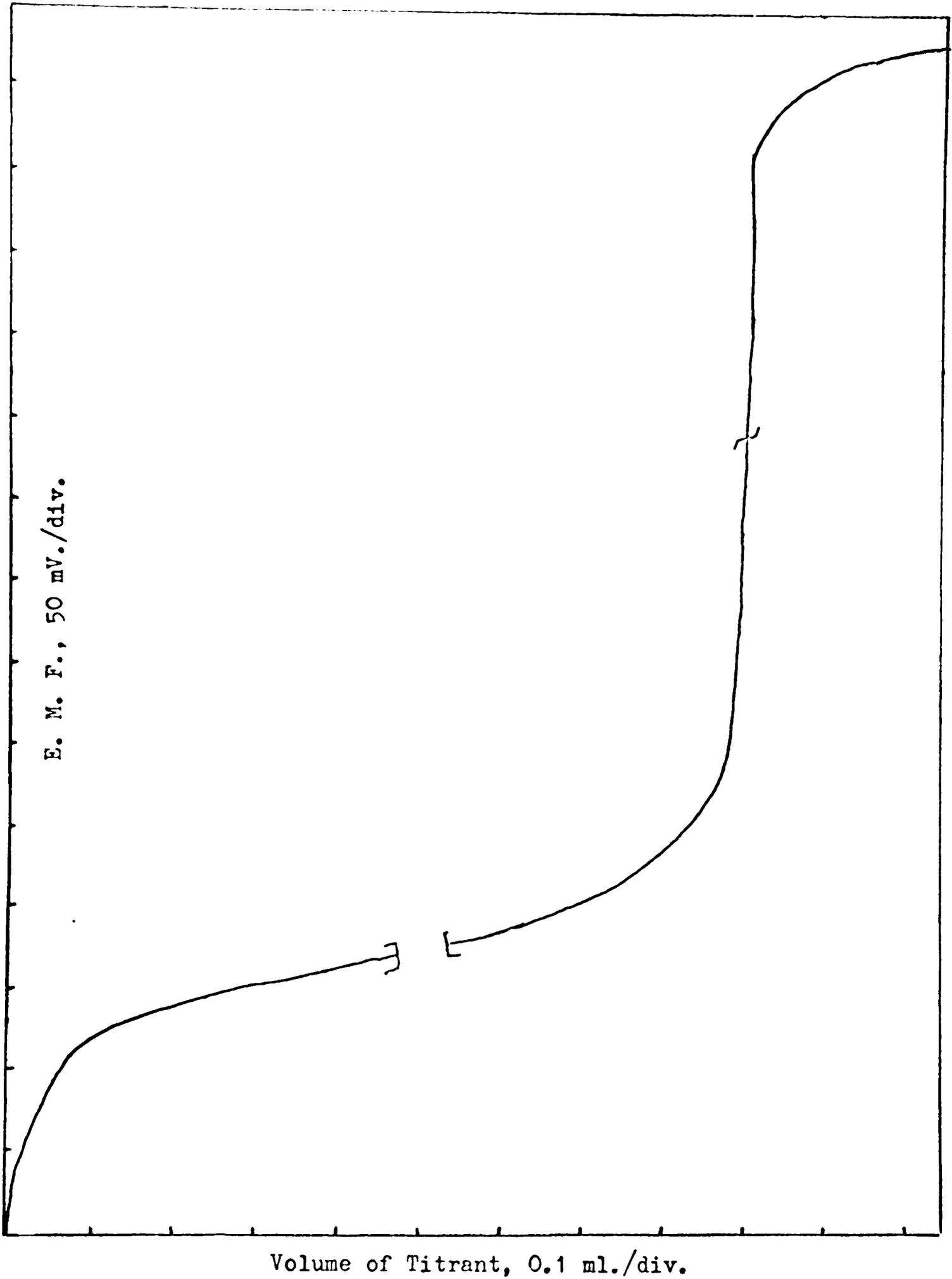


Figure 7. Titration of Benzoic Acid in Pyridine with TBAH:
KCl-ethanol electrode

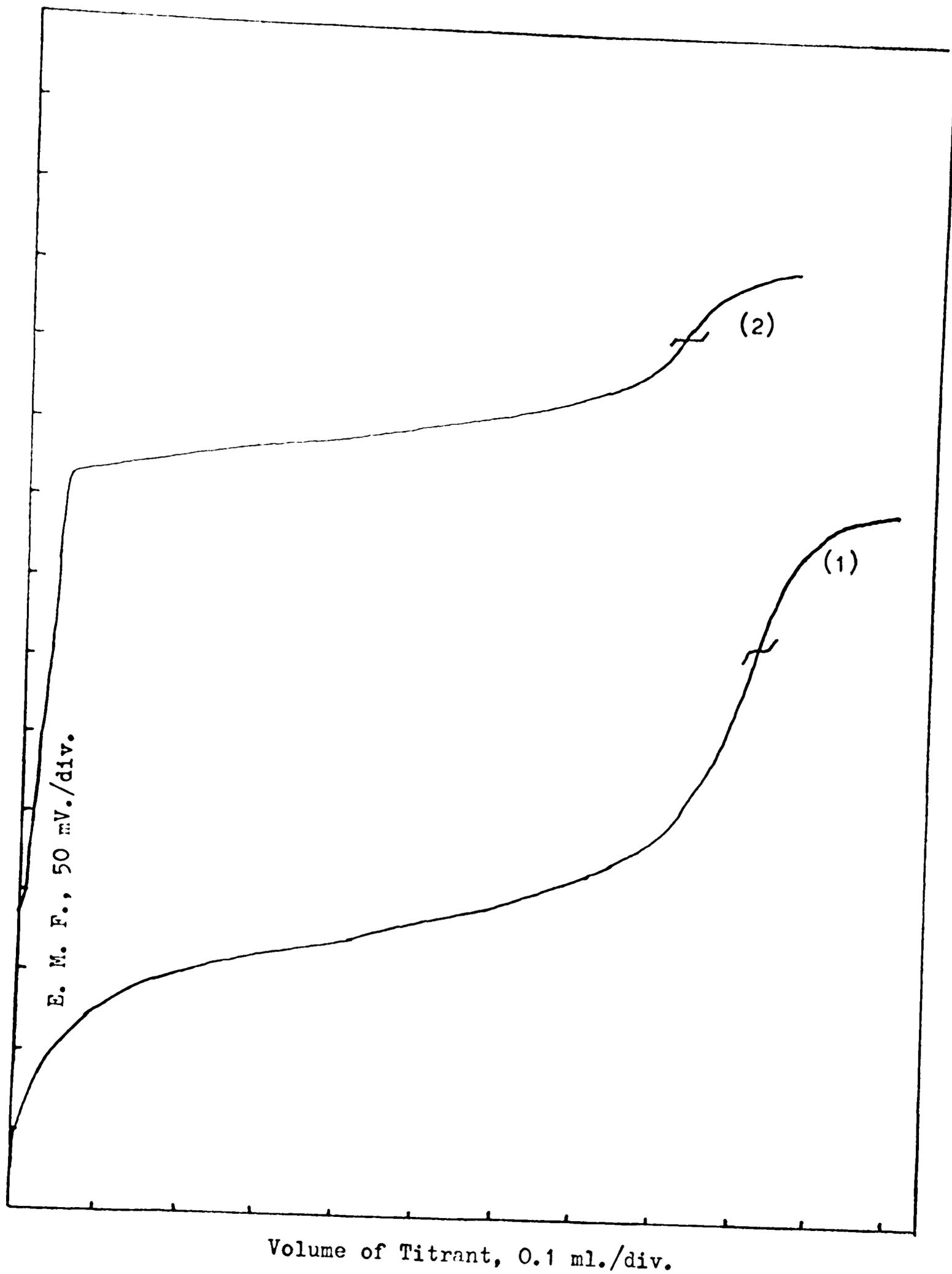


Figure 8. Titration of (1) Carbazole and (2) Indole in Pyridine with TBAH: KCl-ethanol electrode

TABLE I.--Standardization of TBAH with benzoic acid in pyridine solvent using combination electrode^a

| Determination | Normality ^b |
|---------------|------------------------|
| 1. | 0.0777 |
| 2. | 0.0797 |
| 3. | 0.0866 |
| 4. | 0.0833 |
| 5. | 0.0803 |
| 6. | 0.0827 |
| 7. | 0.0777 |
| | Avg. 0.0811 ± 0.0032 |

a Electrolyte: saturated KCl in ethanol

b Solvent blank less than 0.01 ml.

TABLE II.--Titration of weak acids with TBAH in pyridine solvent using combination electrode^a

| Compound | meq. added | meq. found | % purity |
|-----------|------------|------------|----------|
| Carbazole | 0.0646 | 0.0648 | 100.3 |
| Carbazole | 0.0377 | 0.0377 | 100.0 |
| Carbazole | 0.0670 | 0.0732 | 109.3 |
| Indole | 0.0598 | 0.0591 | 98.8 |
| Indole | 0.0682 | 0.0724 | 106.2 |
| Indole | 0.0396 | 0.0421 | 106.3 |
| Phenol | 0.1094 | b | — |

a Electrolyte: saturated KCl in ethanol

b No observable break

It was observed that the TBAH had a yellow tint which intensified with time.

When EDA was used as solvent for the titration, benzoic acid gave no detectable break; therefore, this solvent was abandoned for use with weaker acids. One trial run was made with acetonitrile as the solvent in titrating carbazole; a small break was detected but the error was large (ca. 9 %).

Tetrabutylammonium ethoxide

Several unsuccessful attempts were made at preparing a 0.3 M solution of tetrabutylammonium iodide in benzene, it was found that the salt would not completely dissolve. To dissolve the salt a small quantity of ethanol was added (ca. 10 ml.). Upon addition of 10 ml. of 3 M sodium ethoxide (in ethanol), no precipitation occurred even upon seeding with sodium iodide crystals and chilling in an ice bath. Using the bromide salt, the reaction worked successfully; the bromide was soluble in benzene, and the precipitation of sodium bromide was immediate upon addition of sodium ethoxide. The precipitate; however, was gelatinous and was allowed to set overnight to complete coagulation.

The polarized platinum electrode was again tried, this time in EDA, the solvent with which Heumann reported his best results. There was no detectable break with benzoic acid; the entire titration spanning only 100 mV. The platinum-platinum couple was abandoned.

Using the potassium chloride-ethanol modified combination electrode, attempts were made to titrate benzoic acid in EDA. No detectable breaks occurred, but rather, a slow steady rise in potential

with no leveling off even past 200 % of calculation neutralization occurred. The absence of the break is probably due to the alkali metal error. As Deal and Wyld (39) pointed out, the glass electrode is so insensitive when using titrants containing sodium and very basic solvents, such as EDA, that it can even be used as a reference electrode. The method of preparing TBAE probably leaves a large amount of sodium ion in solution. Pyridine was then tried to find out if this effect could be reduced. Again no detectable break occurred; therefore, the probable cause of no observable break was that the glass electrode, due to the high sodium content of the titrant, did not function as an indicating electrode.

Tetrabutylammonium Hydroxide: Improved

The poor results obtainable with TBAE and the desire for better precision and accuracy than obtainable with the TBAH titrant previously discussed, made it desirable to improve the TBAH method. Two means were tried. A titrant with reduced concentrations of impurities (especially carbonates) was prepared and a reference electrode electrolyte that would have very little alkali metal error, a 0.01 M tetrabutylammonium bromide (TBAB) in ethanol, was prepared. Results obtained were better than any of the other systems tried. In contrast to the previous yellow TBAH, this titrant was water white and remained clear for several weeks.

The first solvent to be investigated for use of this new system was Karl Fischer Grade pyridine. The standardization against benzoic acid gave excellent precision (only 3 parts per thousand relative deviation) as shown in Table III.

TABLE III.--Standardization of improved TBAH against benzoic acid in pyridine

| Determination | Normality |
|---------------|-------------|
| 1. | 0.0789 |
| 2. | 0.0790 |
| 3. | 0.0785 |
| | Avg. 0.0788 |

The solvent blank was less than 0.01 ml. so no correction was made. A typical curve for titration of benzoic acid is shown in Figure 9. The titration of various acids gave better defined curves than any obtainable with previous systems (see Figures 10 and 11). Pyrrole still failed to give a detectable break (Figure 12). A summary of the results is given in Table IV. The degree of reproducibility of the curves was determined by comparing the potential reading at the end point for the compounds benzoic acid, carbazole, and indole. As shown in Table V. the results yielded good reproducibility with an average deviation of values of only 1.7 %. It was noted that in titrating carbazole a yellow color formed upon approaching the end point.

The next solvent tried, tertiary butanol, gave excellent curves with benzoic acid, even better defined than those in pyridine in that the curves were flatter (see Figure 13). The pyridine curves in Figure 8 have a gentle rising slope before the equivalence point whereas tertiary butanol curves have a much flatter slope. Huber (36)

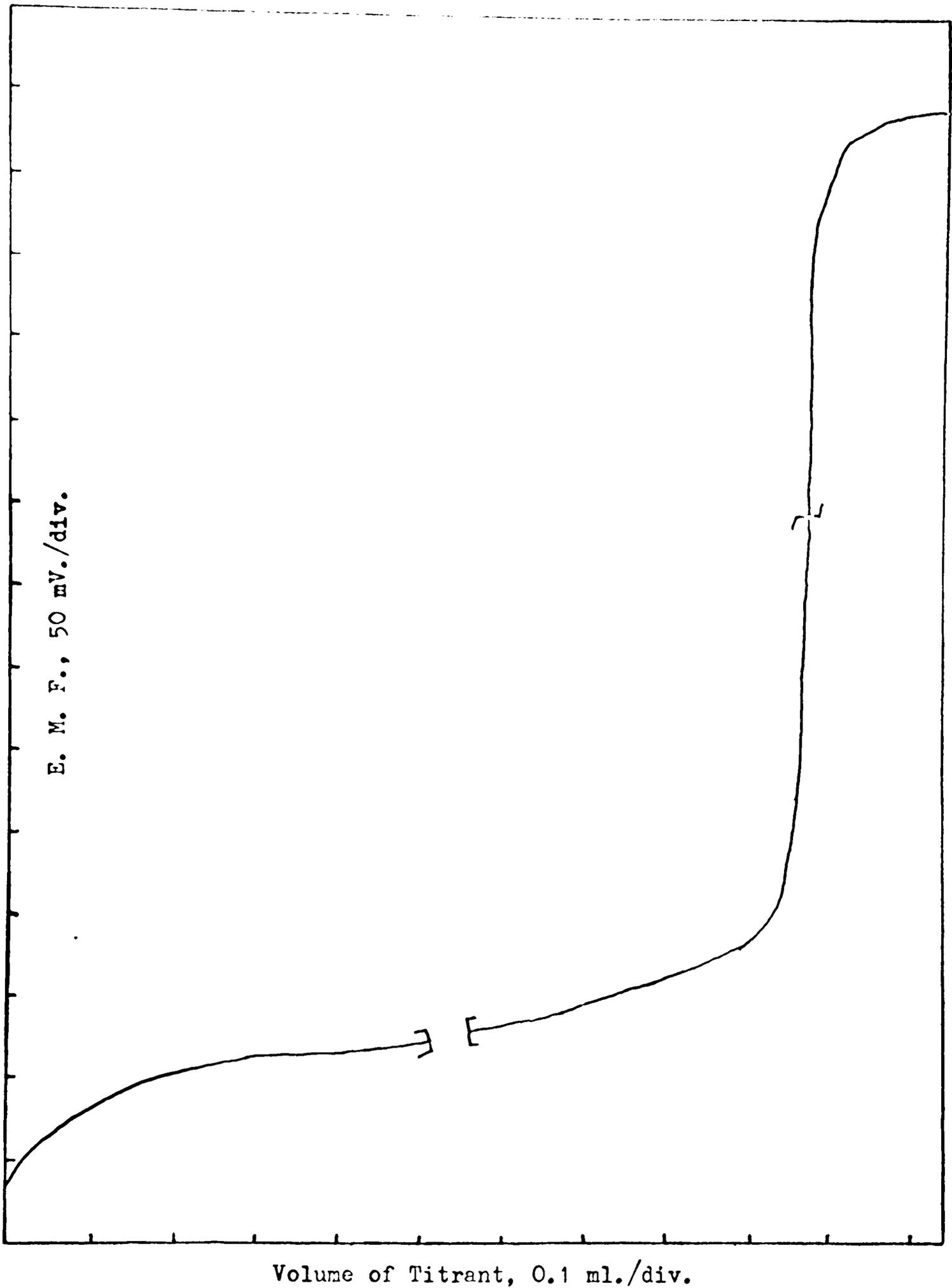


Figure 9. Titration of Benzoic Acid in Pyridine with improved
TBAH: TBAB-ethanol electrode

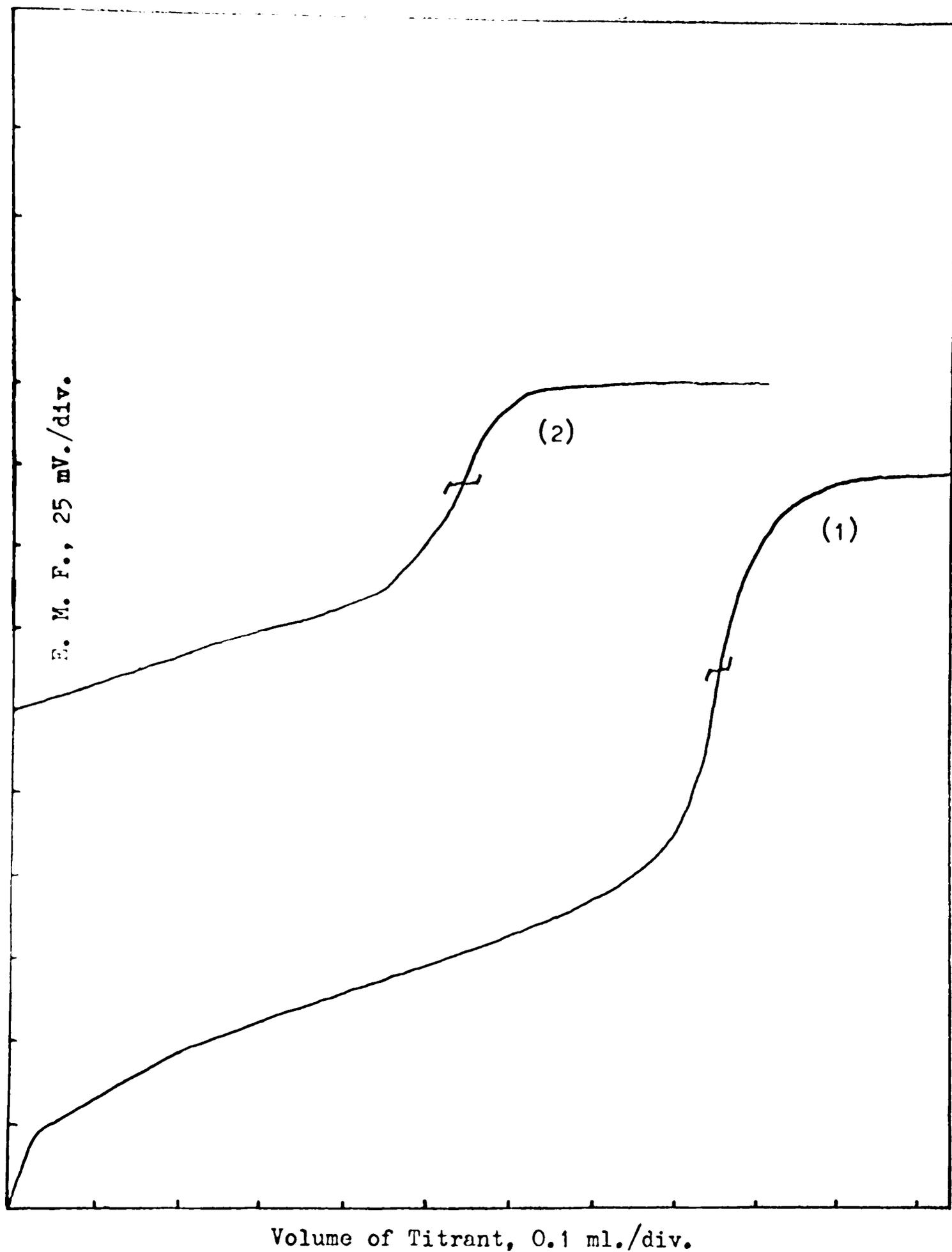


Figure 10. Titration of (1) Carbazole and (2) Indole in Pyridine with improved TBAH: TBAB-ethanol electrode

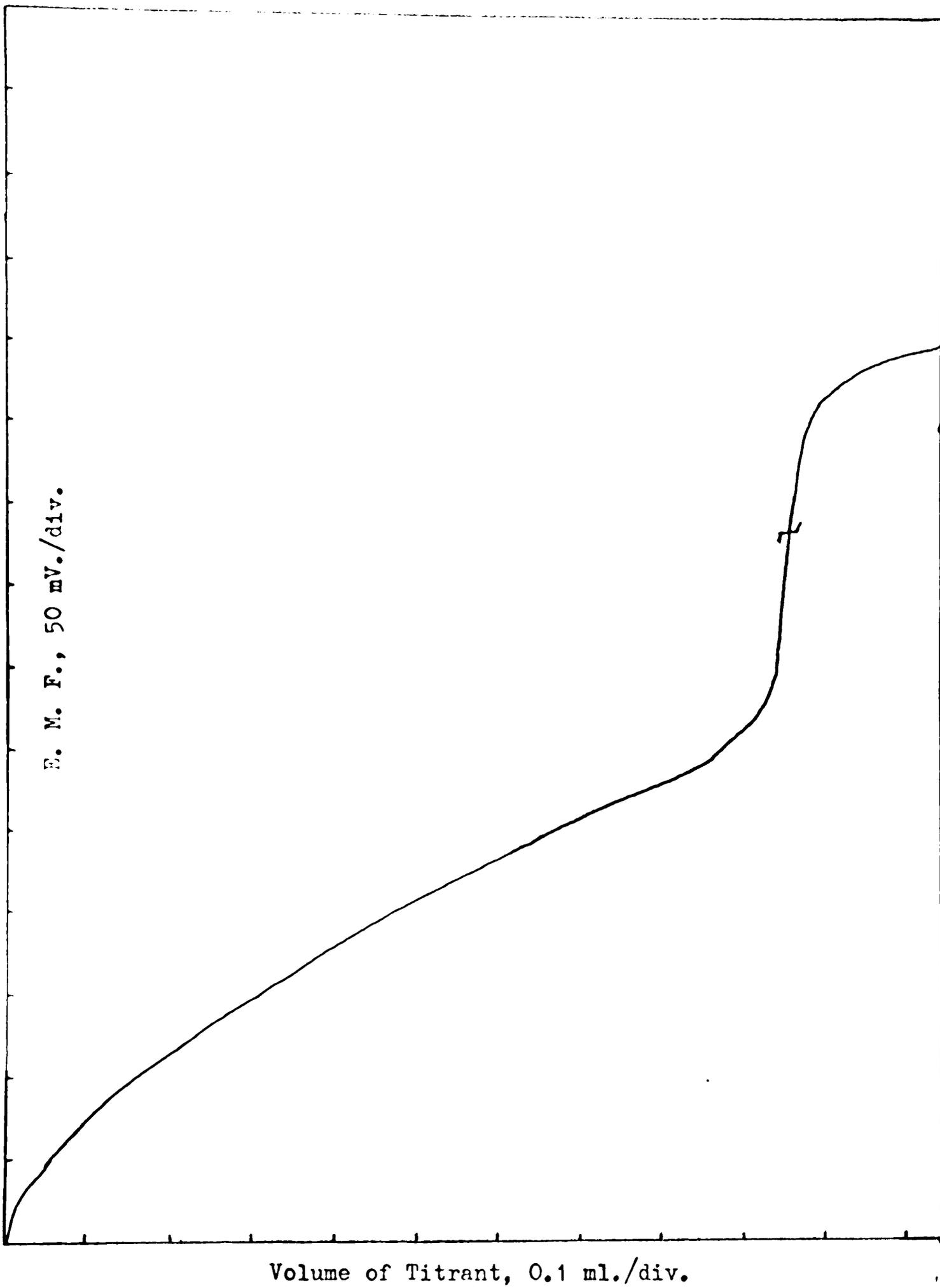


Figure 11. Titration of 2-Naphthol in Pyridine with improved
TBAH: TBAB-ethanol electrode

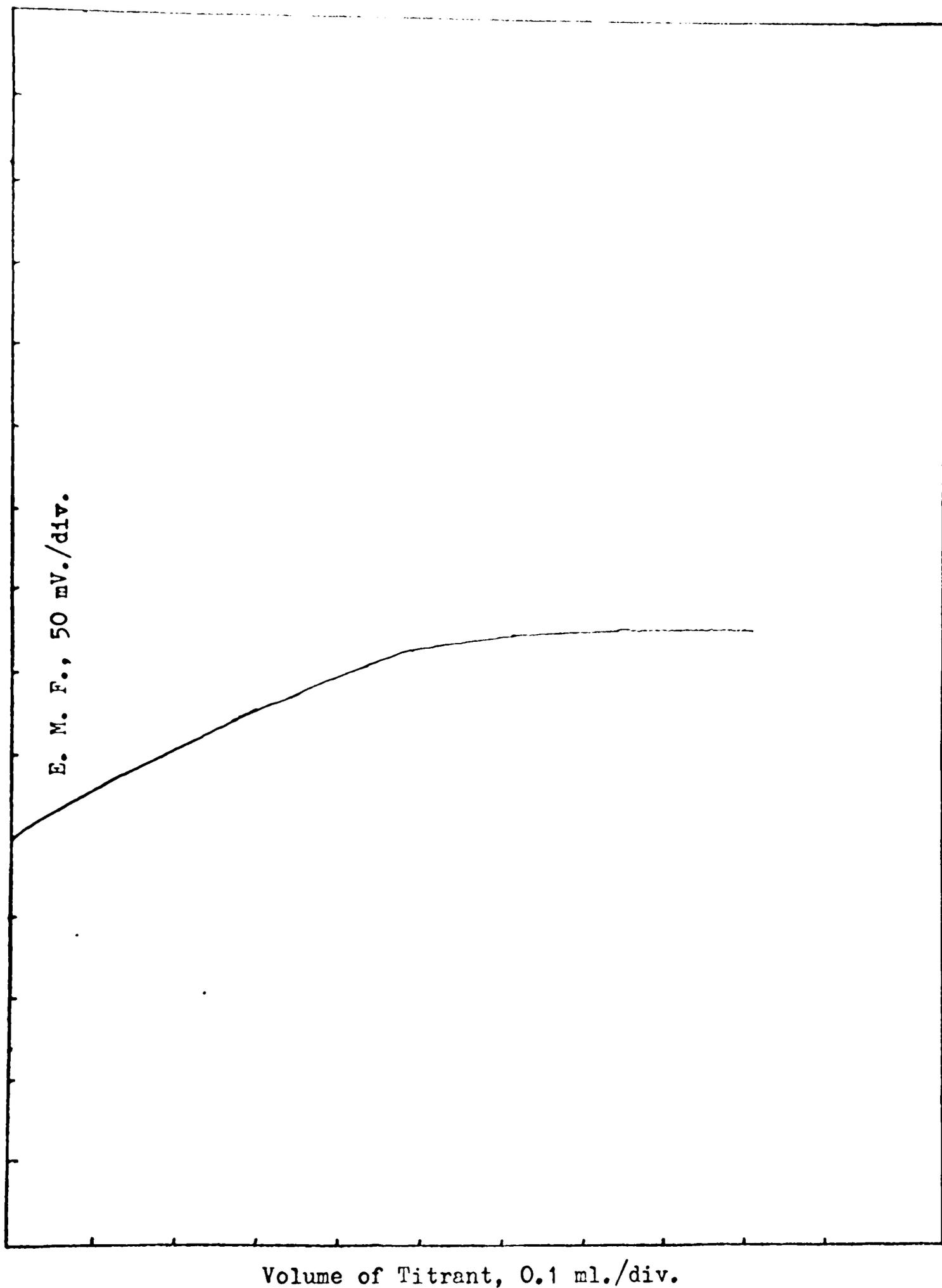


Figure 12. Titration of Pyrrole in Pyridine with improved
TBAH: TBAB-ethanol electrode

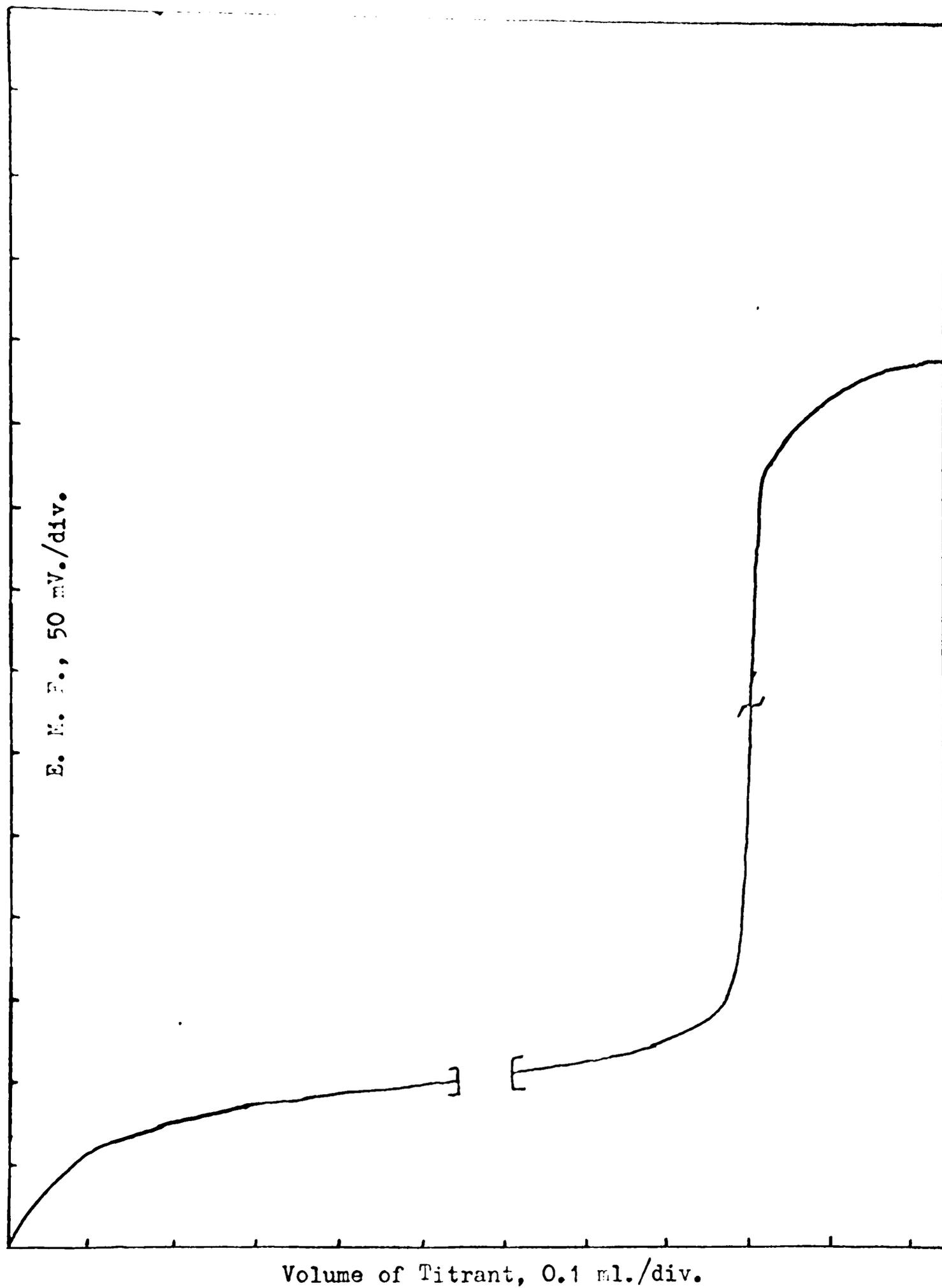


Figure 13. Titration of Benzoic Acid in t-Butanol with improved TBAH: TBAB-ethanol electrode

attributes this flatness of potential curves in tertiary butanol to the fact that hydroxyl groups prevent any association that might result from hydrogen bonding and thus permits better separation of potential plateaus due to substances with different acidities. However, neither carbazole, indole, nor pyrrole gave detectable breaks. The titration of 2-naphthol (pK_a 9.93) gives a fairly well defined break (see Figure 14).

TABLE IV.--Titration of various acids using improved TBAH in pyridine using combination electrode^a

| Compound | meq. added | meq. found | % purity |
|------------------------|------------|------------|----------|
| Carbazole | 0.0772 | 0.0741 | 96.0 |
| Carbazole | 0.0670 | 0.0654 | 97.6 |
| Carbazole | 0.0574 | 0.0599 | 104.4 |
| Indole | 0.0982 | 0.0985 | 100.3 |
| Indole | 0.0640 | 0.0662 | 103.4 |
| Indole | 0.0495 | 0.0504 | 101.8 |
| Pyrrole | b | — | — |
| 2-Naphthol | 0.0756 | 0.0756 | 100.0 |
| Carbazole ^c | 0.0586 | 0.0583 | 99.5 |
| Indole ^c | 0.0666 | 0.0654 | 98.2 |

a Electrolyte: 0.01 M TBAB in ethanol

b No detectable break

c Lowered electrode so as to diminish solvent volume making the concentration of the acid higher

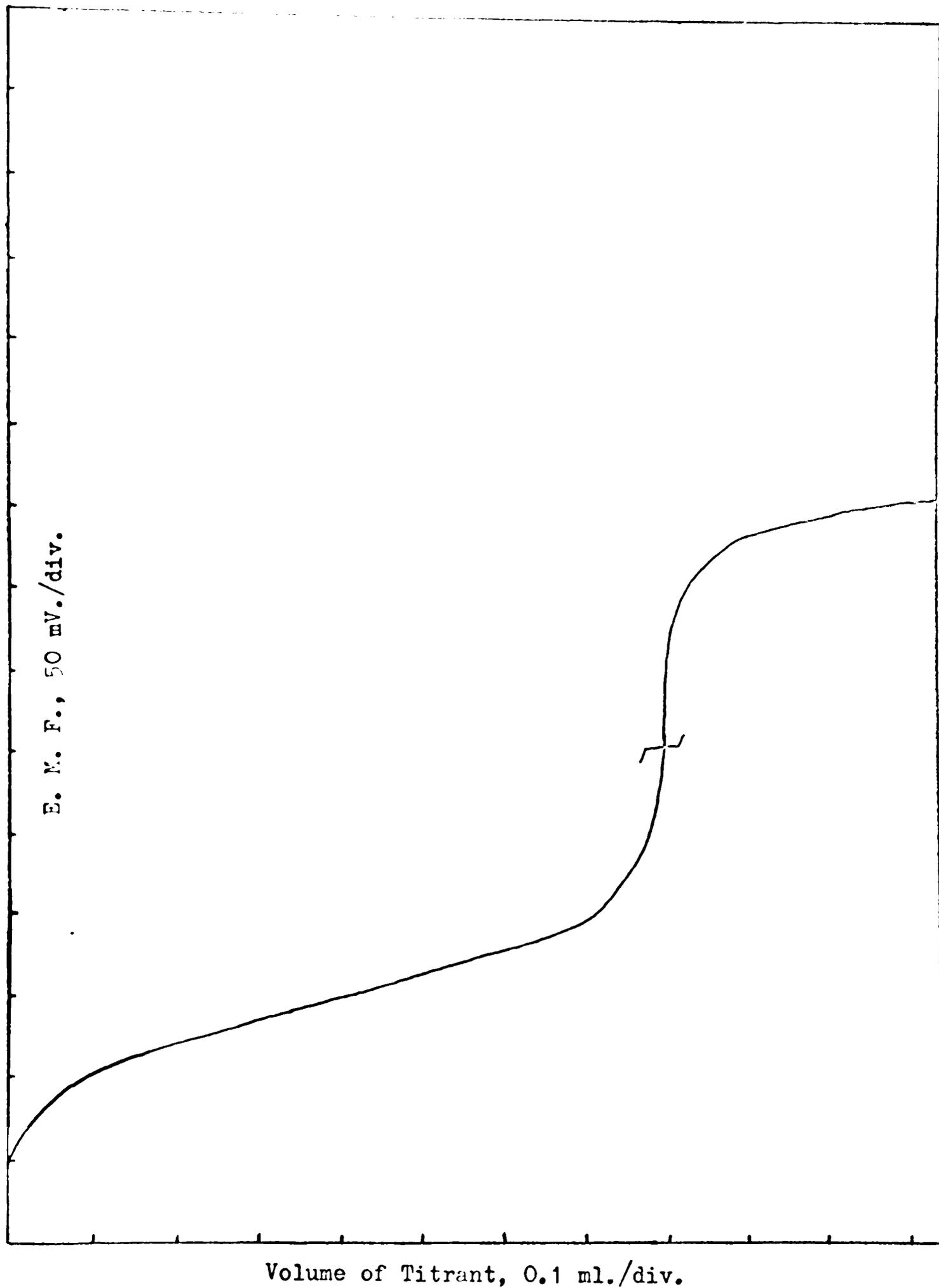


Figure 14. Titration of 2-Naphthol in t-Butanol with improved
TBAH: TBAB-ethanol electrode

TABLE V.—Summary of end point potentials

| Compound | Trial | - mV. end point |
|-----------|-----------------|-----------------|
| Benzoic | 1. | 855 |
| Benzoic | 2. | 900 |
| Benzoic | 3. | 912 |
| | | Avg. 889 |
| Carbazole | 1. | 1033 |
| Carbazole | 2. | 1068 |
| Carbazole | 3. | 1070 |
| Carbazole | 4. ^a | 1082 |
| | | Avg. 1063 |
| Indole | 1. | 1118 |
| Indole | 2. | 1109 |
| Indole | 3. | 1120 |
| Indole | 4. ^a | 1097 |
| | | Avg. 1111 |

a Electrode lowered in the solvent

Ethylenediamine (G. F. Smith Co. grade "for non-aqueous titrations") was the last solvent investigated. Using the TBAB-in-ethanol modified combination electrode, benzoic acid was used as a standard material in the first runs. Three consecutive standardizations gave normalities of 0.0876, 0.0710, 0.0638 which is a relative deviation of 124 parts per thousand. Furthermore the average value for the normality, 0.0741, differs from the value in pyridine, 0.0788, by 6.1%. Breaks were obtained with carbazole but indole and pyrrole failed to give breaks. The results were extremely variant with differences of successive runs being sometimes about 10%. From a

solvent blank, the indications are that the solvent contained some impurity maybe carbonates that gave these non-reproducible results. To try to eliminate any electrode effect a new modification was tried. A lithium chloride saturated solution of ethylenediamine (40) was prepared and used as the electrolyte. The curves obtained with benzoic acid showed no break but rather a gradual rise in potential.

CHAPTER IV

SUMMARY AND CONCLUSIONS

This study has shown the effects upon and the feasibility of the titration of weak acids (pK_a between 9 and 16) with varying combinations of titrant, electrode, and solvent. The accuracy and precision of the various systems were obtained and compared.

The primary concern was whether acids of such weak strength as carbazole, indole, and pyrrole could be titrated accurately using alkoxides of tetraalkyl ammonium salts. Except in the case of pyrrole, it was determined that the titrations were possible.

The titration system that gave the largest, smoothest, and best defined breaks was the improved tetrabutylammonium hydroxide titrant used in combination with the 0.01 M tetrabutylammonium bromide-in-ethanol modified combination electrode. This electrolyte solution (0.01 M TBAB in ethanol) was stable and had to be changed only occasionally. A distinct advantage of this system is the use of the commercially available combination glass electrode which is quite easy to modify as indicated.

The reason for failure of the tetrabutylammonium hydroxide titrant prepared by the silver oxide method is the presence of impurities (principally carbonate) as evidenced by the yellow color of the titrant.

As mentioned previously, the failure of the platinum couple is due to the placement of the reference platinum wire in the solution rather than in the titrant stream. However, limited capacity of the oxygen covering of the indicating electrode probably also has a great deal to do with the non-reproducibility of the potentials. The treatment is also quite troublesome since it must be repeated before each titration.

The failure of the tetrabutylammonium ethoxide titrant was due to the high sodium ion content of the titrant which interfered with the proper functioning of the glass electrode as an indicating electrode.

The failure of ethylenediamine to serve as a satisfactory solvent was due to two reasons. Ethylenediamine markedly reduces the potential span of a titration and has a great tendency to absorb carbon dioxide. The absorption of carbon dioxide gives an uncertain solvent blank which makes reproducibility and precision extremely difficult.

The question can be raised whether pyrrole, carbazole, and indole are all of about the same acidic strength. Under identical conditions both carbazole and indole gave distinct breaks whereas pyrrole did not.

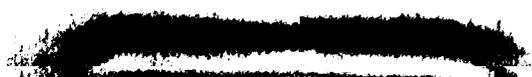
The formation of a yellow color upon nearing the end point of titrations of carbazole in pyridine with TBAH titrant (in 1:10 ethanol-benzene solvent) might possibly be used for a photometric titration.

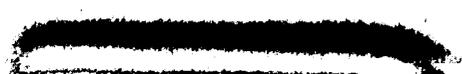
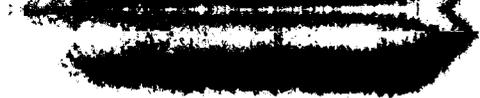
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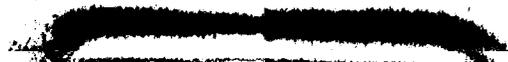
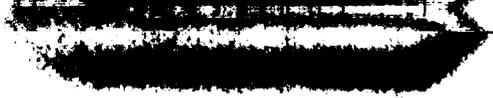
1. Pecsok, R. L. and L. D. Shields, "Modern Methods of Chemical Analysis," John Wiley and Sons, Inc., New York, 1968.
2. Kucharsky, J. and L. Safarik, "Titrations in Non-aqueous Solvents," Elsevier Publishing Co., New York, 1965.
3. Folin, O. and A. H. Wentworth, J. Biol. Chem., 7, 421 (1910).
4. Bishop, E. R., E. B. Kittredge, and J. H. Hilderbrand, J. Am. Chem. Soc., 44, 135 (1922).
5. Seltz, H. and D. S. McKinney, Ind. Eng. Chem., 20, 542 (1928).
6. Seltz, H. and L. Silverman, Ind. Eng. Chem., Anal. Ed., 2, 1 (1930).
7. Clarke, B. L., L. A. Wooten, and K. G. Compton, Ind. Eng. Chem., Anal. Ed., 3, 321 (1931).
8. Ralston, R. R., C. H. Fellows, and K. S. Wyatt, Ind. Eng. Chem., Anal. Ed., 4, 109 (1932).
9. Wooten, L. A. and A. E. Ruehle, Ind. Eng. Chem., Anal. Ed., 6, 449 (1934).
10. Moss, M. L., J. H. Elliott, and R. T. Hall, Anal. Chem., 20, 784 (1948).
11. Brønsted, J. N., Rec. Trav. Chim., 42, 718 (1923).
12. Lowery, T. M., J. Soc. Chem. Ind. London, 42, 43 (1923).
13. Katz, M. and R. A. Glenn, Anal. Chem., 24, 1157 (1952).
14. Fritz, J. S. and N. M. Lisicki, Anal. Chem., 23, 589 (1951).
15. Fritz, J. S. and R. J. Keen, Anal. Chem., 25, 179 (1953).
16. Harlow, G. A., C. M. Noble, and G. E. A. Wyld, Anal. Chem., 28, 784 (1956).
17. Harlow, G. A., C. M. Noble, and G. E. A. Wyld, Anal. Chem., 28, 787 (1956).

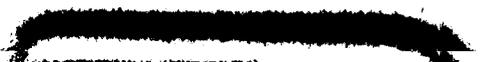
18. Cundiff, R. H. and P. C. Markunas, Anal. Chem., 28, 792 (1956).
19. Cundiff, R. H. and P. C. Markunas, Anal. Chem., 30, 1450 (1958).
20. Fritz, J. S. and L. W. Marple, Anal. Chem., 34, 921 (1962).
21. Marple, L. W. and J. S. Fritz, Anal. Chem., 34, 796 (1962).
22. Morrison, R. T. and R. N. Boyd, "Organic Chemistry," Second Edition, Allyn and Bacon, Inc., Boston, 1966.
23. Cundiff, R. H. and P. C. Markunas, Anal. Chem., 34, 584 (1962).
24. Belcher, R., G. Dryhurst, and A. M. G. MacDonald, Anal. Chim. Acta, 38, 435 (1967).
25. Stamey, T. W., Jr. and R. Christian, Talanta, 13, 144 (1966).
26. Heumann, W. R., "Titrimetric Methods, Proceedings of the Symposium on Titrimetric Methods," D. S. Jackson, ed., Plenum Press, New York, 1961.
27. Lee, D. A., Anal. Chem., 38, 1168 (1966).
28. Buell, B. E., Anal. Chem., 39, 762 (1967).
29. Jewel, D. M. and J. H. Hartung, J. Chem. Eng. Data, 9, 297 (1964).
30. Palmer, M. H., "The Structure and Reactions of Heterocyclic Compounds," Edward Arnold Ltd., London, 1967.
31. Albert, A., "Heterocyclic Chemistry," Essential Books, Fair Lawn, New Jersey, 1959.
32. Corwin, A. H. and R. C. Ellingson, J. Am. Chem. Soc., 64, 2098 (1942).
33. Huber, W., Z. Anal. Chem., 216 (2), 260 (1966).
34. Zonova, Z. T. and M. D. Matveeva, Izv. Akad. Nauk. SSSR, Otd. Tekhn. Nauk., Met. i Toplivo, 1961, No. 5, 150.
35. Vogel, A. I., "Practical Organic Chemistry," Longmans, Green and Co., New York, 1954.
36. Huber, W., "Titrations in Nonaqueous Solvents," Academic Press, New York and London, 1967.
37. Harlow, G. A. and G. E. A. Wyld, Anal. Chem., 34, 172, (1962).
38. Van der Heijde, H. B., Anal. Chim. Acta, 16, 392 (1957).

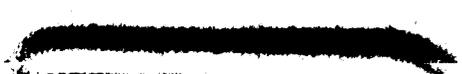
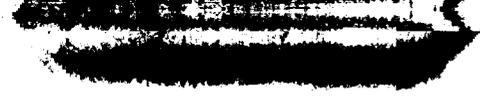
39. Deal, V. Z. and G. E. A. Wyld, Anal. Chem., 27, 47 (1955).
40. Gran, G. and B. Althin, Acta Chem. Scand., 4, 967 (1950).

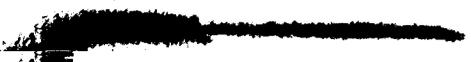


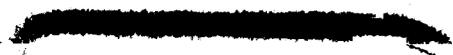








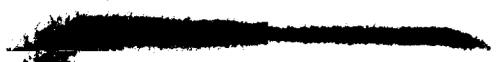


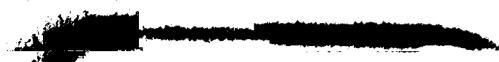


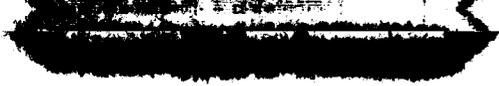


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