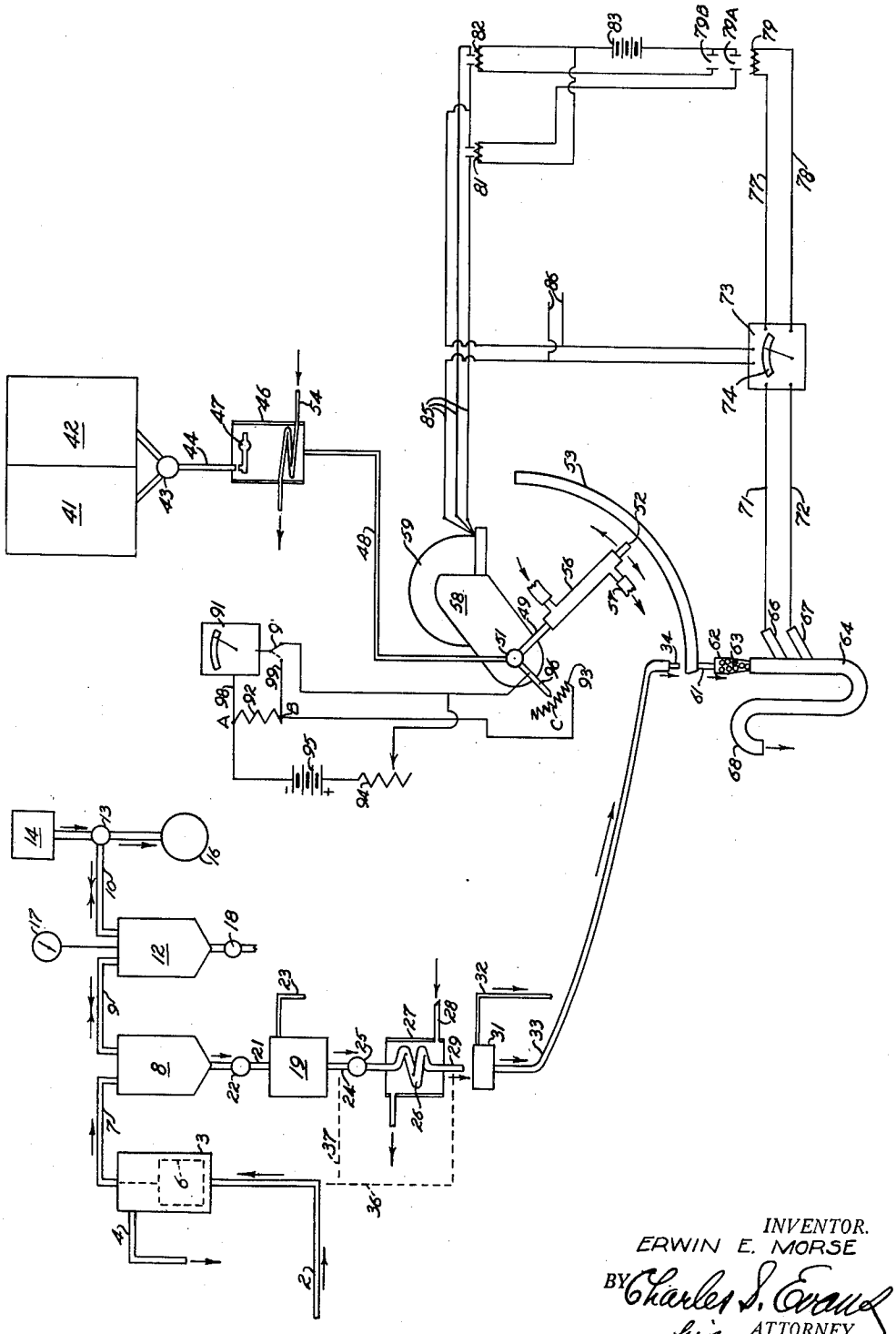
July 22, 1952 E. E. MORSE 2,604,383

CONTINUOUS TITRATION APPARATUS

Filed March 16, 1946



INVENTOR.
ERWIN E. MORSE
BY Charles S. Evans
his ATTORNEY

Patented July 22, 1952

2,604,383

UNITED STATES PATENT OFFICE

2,604,383

CONTINUOUS TITRATION APPARATUS

Erwin E. Morse, Woodland, Calif.

Application March 16, 1946, Serial No. 654,927

12 Claims. (Cl. 23—253)

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The invention relates to apparatus for performing continuous titration.

One of the most important processes in the field of chemistry is that of titration. In this process, the concentration of a dissolved substance in solution is determined by measuring the smallest amount of it required to bring about a given effect in reaction with another solution or substance. In performing any titration, the chemist must have some means of determining the point of equivalence of the two reacting chemicals. In certain cases where one of the reactants serves as its own "indicator," this can be seen by a sudden change in the color of the reacting solutions. In other cases, completion of titration is indicated by a change in the color of a third substance.

Since the process of titration is a chemical one, with associated changes in physico-chemical properties of the solution, the variation in the magnitude of these properties can often be used as an indirect indicator of the completeness of titration. An important type of indirect indicator which functions by means of a change in a physico-chemical property of the solution is the galvanic cell, which produces a small but definite electromotive force, the value of which depends on the chemical state of the solution. The choice of electrodes for the galvanic cell is determined by the particular titration reaction under consideration. In my present invention I make use of a galvanic cell, activated by the solution under examination, to initiate the operation and control of devices for carrying on continuously and automatically, and recording a titration process of special usefulness in the manufacture of beet sugar.

It is therefore a broad object of my invention to provide an apparatus and process for performing an automatic and continuous titration of an acid solution with an alkaline solution; or of an alkaline solution with an acid solution. It is also an object of my invention in a narrower sense to provide a means for and method of automatically and continuously controlling, measuring and recording the alkalinity of the first carbonation filtrate in the manufacture of beet sugar.

The invention possesses other valuable features, some of which with the foregoing will be set forth at length in the following description where that form of the invention which has been selected for illustration in the drawings accompanying and forming a part of the present specification is explained. In said drawings, one form of the invention is shown, but it is to be understood that it is not limited to that form, since the

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invention as set forth in the claims may be embodied in a plurality of forms.

In the drawings, the figure is a diagrammatical view of the entire apparatus of my invention.

While it will be obvious that my invention may be adapted and applied in many different manufacturing and production arts, its application in the making of beet sugar will be treated in the following explanation of my invention.

In the production of sucrose from sugar beets, one of the most important steps in the process is the defecation of diffusion juice with milk of lime and carbon dioxide. The first part of the defecation process is termed "first carbonation." The mixture obtained from the mixing of diffusion juice, milk of lime or saccharate milk, and carbon dioxide is called first carbonation juice. Probably the most important controlling variable in the first carbonation process is the alkalinity of the filtered juice.

The determination of alkalinity is simply a titration of an alkaline solution with an acid solution. The filtered first carbonation juice is the alkaline solution; and 0.0357 normal sulfuric acid is the acid solution. The strength of the acid is so chosen that when a 10 milliliter sample of the filtered juice is taken, the volume of acid required for neutralization, divided by 100, is the numerical measure of the alkalinity. Furthermore, the alkalinity equals the number of grams of calcium oxide per 100 milliliters of juice, assuming that calcium hydroxide is the only alkali present in the juice.

First carbonation control depends primarily upon the determination of the alkalinity which is made manually by the carbonation operator. Thus the operator takes a sample of first carbonation juice from the carbonation tanks, filters the juice and titrates a 10 milliliter sample of the filtrate with 0.0357 normal sulfuric acid, using phenol-phthalein as a color indicator. If the measured alkalinity of the juice varies from the desired figure, the addition of the milk of lime or carbon dioxide gas is changed so as to obtain the desired figure.

Approximate alkalinity control is frequently obtained by the use of intermediary devices such as pH or conductivity controllers. The principal objection to these devices is that other factors such as temperature or percentage of lime may alter the relationship between alkalinity and pH or alkalinity and conductivity.

Referring to the drawing, a continuous flow of first carbonation juice passes through sample line 2, into the filter pot 3, then out the overflow

pipe 4 and back to the process. If the Dorr system of continuous first carbonation is used, it is convenient to connect sample line 2 to the pressure side of the recirculation pump. With other carbonation systems, the sample line should be so installed that the sample is representative of the completely limed and carbonated juice. A filter 6 consisting of a perforated cylindrical frame covered with a filter medium such as 16-ounce duck filter cloth is immersed in the juice, and connected by pipe 7 to a filtrate receiver 8. A filtration area of 25 square inches is usually satisfactory under normal operating conditions.

The filtrate receiver 8 is also connected through the pipes 9 and 10, between which a trap 12 is interposed, and through the three-way reciprocating valve 13, alternately with a pressure tank 14 and a vacuum tank 16. The trap protects the valve from the juice in the vacuum phase of its operation; and provides a convenient place for mounting a gauge 17, on which the degree of vacuum and the amount of pressure in the connecting lines may be indicated. The trap is also provided with a drain valve 18 at its lower coned end.

The vacuum may be conveniently set at 3 inches of mercury for 17 seconds and the pressure at 1 lb. per sq. in. for 7 seconds. The filtered juice collects in the filtrate receiver 8, while the vacuum is being applied to the system and is blown into the supply tank 19 through the connecting pipe 21, when pressure is applied to the filter. Simultaneously the layer of solid matter which collects on the filter surface during the vacuum part of the filtration cycle is blown off. Admission of air to the filtrate receiver 8 is prevented during the vacuum part of the cycle by the check valve 22, interposed in the pipe 21.

The supply tank 19 is provided with an overflow pipe 23, to a waste return line; and the tank is advantageously made of such a size that the retention time of the juice in the tank is short. A volume of 135 milliliters below the overflow level is a satisfactory value for first carbonation juice.

Connected to the bottom of the supply tank 19 by a pipe 24, controlled by a valve 25, are the coils 26 of a heat exchanger 27, to which a cooling medium is supplied through the pipe 28. Again, it is advantageous to construct the heat exchanger so that the minimum volume of juice commensurate with adequate cooling is present in the cooling coil at any time. 8 ft. of ¼" outside diameter copper tubing is satisfactory for first carbonation juice if the cooling medium is water at 20° C.

The filtrate flows at a steady rate through the valve adjusted passage of the pipe 24, and into the heat exchanger, from which the cooled filtrate flows through the pipe 29 to the constant level tank 31, provided with an overflow pipe 32 to the waste return line. The tank is mounted for vertical adjustment so that the head of filtrate discharging from the bottom thereof through the flexible conduit 33 may be varied. The discharge conduit 33 terminates in a restricted orifice conveniently provided by a piece of capillary glass tubing 34, in adjustably fixed position and having an internal diameter of .044" and a length of 1".

The constant level tank should be quite small so that the retention time of the juice flowing through it is reduced to a negligible amount. A volume of 20 milliliters or less above the outlet to the discharge tube 33, and below the overflow level, is satisfactory for first carbonation juice.

The flow of cooled, filtered juice to the constant level tank 31 is conveniently set at about 150 milliliters per minute by adjustment of the filtrate throttling valve 25. The juice flows through conduit 33 and is delivered from the restricted orifice of the tube 34, held by any suitable means in a fixed position. The rate of flow of the liquid is determined by the dimensions of the capillary tip and the static head of the liquid column above this orifice, it being assumed that the temperature of the liquid remains constant. By varying this static head, the rate of flow may be set at any desired value. A convenient rate of flow with first carbonation filtrate is 75.0 milliliters per minute.

In some titrations there may be no need to filter and cool the material to be analyzed. In that case, the sample to be tested will run continuously from the sample line 2, through the pipe 36, indicated in dashed lines, into the constant level tank 31. If the material is hot or if it has a varying temperature, the sample may be admitted through pipe 37 into pipe 24, above valve 25. The automatic titration may be conducted at any of many different temperatures. The range of 20°–25° C. is convenient for most titrations.

Means are provided for supplying a flow of acid solution and mixing it with the flow of juice, automatically controlling the amount of acid by means responsive to the galvanic current generated by the mixture functioning as an electrolyte in a galvanic couple. A pair of acid tanks 41 and 42 are connected through the three-way valve 43 and pipe 44 to discharge into the constant level tank 46. Constant level is maintained by means of a glass float valve 47. The use of either of two tanks, makes continuous operation possible since acid may be withdrawn from one while the other is replenished.

From the constant level tank 46, the acid flows through the conduit 48 to the inner end of a dispensing tube 49, to which it is flexibly connected, and which is mounted for movement like the hand of a clock on the pivot shaft 51. The tube is provided with a capillary tip 52 and may have an internal diameter of .044" and be 1.13" long. The acid flows through the dispensing tube by gravity to drop from the capillary tip into an arcuate trough 53, fixed below the capillary tip throughout its range of movement in the lower right quadrant of a circle, concentric with the shaft 51. It will be clear that the angular position of the dispensing tube 49 determines the head of liquid above the tip 52, and hence if temperature and composition be constant, the rate of flow from the tip, so that for each angular position of the dispensing tube, there is a corresponding volume flow of acid.

It is desirable to maintain the acid solution at a nearly constant temperature of plus or minus 1 to 2 degrees C. This may be done by immersing cooling coils 54 in the constant level tank 46, and by circulating cooling water through a jacket 56 surrounding the dispensing tube, and connected by flexible conduits 57 with the necessary facilities.

For the titration of first carbonation filtrate, it is preferred to have the distance between the center of the pivot shaft 51 and the capillary tip 52 about 20". The speed of rotary movement of the pivot shaft is of course quite slow; and may be arranged at about .015 R. P. M. by the

use of suitable reduction gearing 58, driven by the reversible synchronous electric motor 59.

The alkaline first carbonation filtrate is conveniently added to the acid at the lower end of the acid trough, the adjustably fixed discharge tube 34 being positioned immediately above the end of the trough, so that filtrate and acid pass together through the discharge nipple 61 into the mixing tube 62, in which mixing is insured by allowing the acid and alkali to flow over about a dozen small glass beads 63, which may conveniently be about .12'' in diameter.

The mixture of acid and alkali is next passed by or through a detecting element which determines whether equivalent amounts of acid and alkali are present. Any of a number of different galvanic cells may be used to measure the hydrogen ion activity in the solution. Examples of these cells are the antimony-calomel cells and the glass electrode-calomel cells. Inasmuch as the hydrogen ion activity (expressed as pH, the log of the reciprocal of hydrogen ion activity) is the most direct and exact measure of the degree of neutralization, it is preferred to use a galvanic cell composed of a glass electrode and a saturated calomel electrode as the detecting element.

This detecting element is conveniently placed in a pH pot 64 having the shape shown in the drawing. This is made of metal to protect the electrodes from mechanical and electrical disturbances. The electrodes are placed in side arms 66 and 67 so that the tips of the electrodes project into the stream of liquid flowing through the pH pot. The discharge tube 68 of the pH pot is so arranged that the level of the solution is maintained about ¼'' above the upper or glass electrode bulb; and the internal diameter of the pH pot should be about ½'' so as to keep the volume of solution in the pot at a minimum value.

There should be the least possible distance between the bottom of the trough 53 and the glass electrode in side arm 66. Therefore nipple 61 and tube 62 should be of minimum length and the glass electrode should always be placed in the uppermost side arm of the pH pot. Within 5 seconds after a change in the flow of acid there should be an indicated change in the pH of the mixture in pH pot 64.

Means are provided for measuring the E. M. F. produced in the cell, and for utilizing this current to control motor means responsive to its variations, to swing the dispensing tube to vary the volume of acid dropping into the trough.

The electrodes of the cell are connected by leads 71 and 72 to an automatic pH indicator 73 such as Beckman's model R. This instrument measures the electric potential produced by the electrodes; and its scale 74 is calibrated in pH values corresponding to such potential, so that the pointer at all times indicates the pH condition in the pot. The instrument is provided with terminals by which an additional indicating meter at a remote point may be connected; and I make use of these terminals to connect, by means of leads 77 and 78, a highly sensitive moving coil relay 79. This relay makes contact on one side when the current flowing through the coil is reduced and on the other side when the current is increased. Inasmuch as the magnitude of the current depends on the pH of the mixture of the acid and alkali, it is evident that the operation of the sensitive moving coil relay depends on this pH value.

The relay 79 in turn controls two relays 81 and 82, operated by current from a battery 83. Relay 81 functions when relay 79 makes contact on the low side 79A and relay 82 functions when relay 79 makes contact on the high side 79B. Neither relay 81 nor 82 will function when the moving contact of relay 79 is in its intermediate position.

Connected by the leads 85 to the power line 86 for control by the relays 81 and 82 is the reversible synchronous electric motor 59. Limit switches of conventional design, not shown, are provided to control the rotation of the motor, to keep movement of the dispensing tube 49 within its permissible range in the quadrant selected for its operation.

The operation of the apparatus as so far described is as follows: It is assumed that first carbonation juice is flowing through the filter pot 3; that pressure and vacuum are alternately being supplied to the filter 6; that cooling water is being supplied to the heat exchanger 27; and that the static head on the orifice of the discharge tube 34 is adjusted so that the desired flow of first carbonation filtrate is being obtained. Furthermore, it is assumed that the potentiometer 73 is so adjusted that the moving contact of relay 79 is in its intermediate position when the pH of the acid-alkali mixture flowing through the pH pot 64 has that value corresponding to the presence of chemically equivalent amounts of acid and alkali. For first carbonation filtrate and 0.0357 normal sulfuric acid, it has been found that this pH value is 7.08 at 25° C. This adjustment of the electronic potentiometer is readily made.

Under these conditions, a stream of cooled first carbonation filtrate will be delivered from the discharge tube 34, at a constant rate and mixed with the acid solution flowing from the restricted orifice or capillary tip 52. If chemically equivalent amounts of alkali and acid are present in the two streams, the mixture will be chemically neutral and have a pH value of 7.08. The moving contact of the sensitive relay 79 will hence lie in its intermediate position and neither relay 81 nor relay 82 will operate, so that the shaft 51 is at rest. If, however, the mixture of acid and alkali contains an excess of alkali, the pH of the mixture will be greater than 7.08 and the moving contact of the relay 79 will make contact on the side 79B; and this in turn will cause relay 82 to close. In turn, the reversible motor will operate so as to rotate the shaft 51 in a clockwise direction. This will increase the static head of the acid column on orifice 52, and hence the flow of the acid solution will increase. When the rate of flow of the acid is such that the mixture of acid and alkali is chemically neutral or the pH is reduced to 7.08, the moving contact of relay 79 will seek the intermediate position, relay 82 will become inoperative and motor 59 will stop. The dispensing tube 49 then remains at rest; and the rate of flow of the acid solution is constant.

Suppose now that the alkalinity of the first carbonation filtrate is reduced. The chemical balance is again upset and the mixture of acid and alkali flowing through the pH pot becomes more acid, or the pH value decreases. This drop in pH finds immediate response in the potentiometer; and the moving contact of the relay 79 makes contact on the side 79A. This causes relay 81 to function and the motor operates to rotate shaft 51 in a counter-clockwise direction. The static head of the acid column on orifice 52 is

lessened and consequently the flow of acid is reduced. Equilibrium between the acid and alkali is thus again attained, the pH of the mixture equals 7.08 and the dispensing tube **49** again comes to rest. Thus the flow of acid is subject to constant and automatic variation so as to maintain the chemical balance between acid and alkali.

From the above description it will be obvious that my continuous titration apparatus is not necessarily restricted to the use of a constant flow of alkali and a variable flow of acid. The acid flow could be made constant and the alkali flow varied. Similarly, if an acid solution of unknown composition were being analyzed, this solution could be run through the apparatus at a constant rate while varying the flow of a solution of alkali of known strength or the alkali solution could be used at a constant rate of flow, while the rate of flow of the acid solution was varied. In general, if V_A and N_A are the volume in milliliters per minute and the concentration in equivalents per liter for the acid and V_B and N_B are the corresponding quantities for the alkali, the condition for equilibrium is that $V_AN_A=V_BN_B$. It can be readily seen that if any two of these quantities are fixed in value, the values of the other two quantities bear a direct relationship to one another. Thus if V_B and N_A are fixed in value, N_B bears a direct relationship to V_A. This is the case in which the rate of flow of the alkali and the strength of the acid are held constant. Then the strength of the alkali is directly proportional to the flow of acid. We might also hold V_A and N_A constant, in which case N_B is inversely proportional to V_B.

We will assume that the automatic titrimeter is being used as first described, namely with a constant flow of alkali and a variable flow of acid, the alkali being of varying strength and the acid of constant strength. The flow rate of the acid is then a measure of the strength of the alkali.

Means are provided for measuring and recording the flow rate of acid. Such means include a recording potentiometer **91**, a 50-ohm resistance **92**, a variable 50-ohm resistance **93**, a variable 150-ohm resistance **94**, and a 1.5 volt battery **95**, in a circuit as shown in the upper part of the figure. A contact arm **96**, fixed for movement with the shaft **51** and dispensing tube **49**, ranges over the resistance **93**; and a single pole double throw switch **97** permits connection of the potentiometer **91** across the resistance **92** through leads **98** and **99** or across resistance **92** plus that portion of resistance **93** included in the circuit by the contact arm **96**. The battery **95** supplies the current and the variable resistance **94** permits adjustment of the current to a value of .007 ampere.

This adjustment is made by throwing switch **97** to the left so that the potential drop between points A and B is measured. Inasmuch as the value of resistance **92** is 50 ohms, the value of resistance **94** may be adjusted so that the observed potential drop is 0.350 volt. When switch **97** is thrown to the right, the potential drop between points A and C is measured.

It is now obvious that for every position of the output shaft **51** there will be a corresponding flow of acid from orifice **52**, and a corresponding position of the contact arm (position C) on resistance **93**. The potential drop across AC is therefore a direct measure of the flow of acid and in turn this is a measure of the alkalinity of the first carbonation juice. It is thus possible to calibrate the recording potentiometer directly in terms of alkalinity, simply by measuring the flow of acid for several different positions of the acid delivery tube **49**. Knowing the strength of the acid and the flow of the first carbonation juice, the alkalinity of the juice is easily calculated.

The values .007 ampere and .35 volt referred to above are not limiting or generally definitive, but merely those actually used in an apparatus embodying my invention, and on which the potentiometer **91** measured a minimum potential drop of .35 volt. With another potentiometer, different values might be necessary for correct operation.

I claim:

1. In titration apparatus, a movable liquid dispensing means movable to vary the static head and thus the amount of liquid discharging therefrom, means including a constant level device for maintaining a continuous supply of the liquid to said dispensing means, a reaction chamber for receiving said liquid, means for introducing in constant volume flow a second liquid into said chamber, a pair of electrodes arranged in the chamber to form with the liquid therein a galvanic cell, and means including means responsive to variation in the output current of said cell for moving said dispensing means.

2. In titration apparatus, a chamber for holding liquid, movable means for introducing liquid in a variable volume flow into said chamber, means for introducing in constant volume flow a second liquid into said chamber, a pair of electrodes arranged in the chamber to form with the liquid therein a galvanic cell, means including means controlled by the output current of said cell for controlling said movable means to control the volume of liquid introduced thereby into said chamber, an electric circuit, a recording potentiometer in said circuit, a variable resistance in said circuit with said potentiometer, and means connected to and actuated by said movable means for controlling said variable resistance and thus the current flow in said circuit to said potentiometer.

3. In a titration apparatus, a movable liquid dispensing means movable to vary the static head and thus the amount of liquid discharging therefrom, said dispensing means having a restricted outlet means including a constant level device for maintaining a continuous supply of the liquid to said dispensing means, a reaction chamber for receiving said liquid, means for introducing in constant volume flow a second liquid into said chamber, a pair of electrodes arranged in the chamber to form with the liquid therein a galvanic cell, a motor operatively connected to the dispensing means to move the same, means including relay-controlled circuits for controlling the motor, and means responsive to the output current of said cell for selectively operating said relays.

4. In a titration apparatus, a movable liquid dispensing means movable to vary the static head and thus the amount of liquid discharging therefrom, means for maintaining a continuous supply of the liquid to said dispensing means, a reaction chamber for receiving said liquid, means for introducing in constant volume flow a second liquid into said chamber, a pair of electrodes arranged in the chamber to form with the liquid therein a galvanic cell, means including means responsive to variation in the output current of said cell for moving said dispensing means, a recording potentiometer, a resistance in circuit therewith, and means connected for movement

with the liquid dispensing means for varying the resistance.

5. In a titration apparatus, a pivotally mounted shaft, a movable dispensing tube fixed radially on said shaft for movement therewith to various angular positions, means connected to said tube for supplying a liquid thereto and positioned to give a constant head at the point of said connection, the angular position of said tube regulating the static head of said liquid and thus the rate of flow of said liquid through said tube, a chamber for holding liquid, means for conducting liquid discharging from the dispensing tube at angularly adjusted positions to the chamber, means for introducing into said chamber a constant volume flow of a second liquid, a pair of electrodes arranged in the chamber to form with the liquid therein a galvanic cell, a reversible motor drivably connected to said shaft, normally open circuits for supplying electrical energy to said motor, means selectively responsive to the output current of said cell for closing one of said circuits to energize the motor to turn the shaft to vary the angular position of said tube, and means for measuring the rate of flow of the liquid passing through said dispensing tube.

6. In a titration apparatus, a pivotally mounted shaft, a movable dispensing tube fixed radially on said shaft for movement therewith to various angular positions, means connected to said tube for supplying a liquid thereto and positioned to give a constant head at the point of said connection, the angular position of said tube regulating the static head of said liquid and thus the rate of flow of said liquid through said tube, a chamber for holding liquid, means for conducting liquid discharging from the dispensing tube at angularly adjusted positions to the chamber, means for introducing into said chamber a constant volume flow of a second liquid, a pair of electrodes arranged in the chamber to form with the liquid therein a galvanic cell, a reversible motor drivably connected to said shaft, normally open circuits for supplying electrical energy to said motor, a prime relay for closing each of said circuits, relay means for operating each of said prime relays, means responsive to the output current of said cell for selectively operating the relay means to operate one of the prime relays to close a circuit to energize the motor to turn the shaft to vary the angular position of said tube, and means for measuring the rate of flow of the liquid passing through said dispensing tube.

7. In a titration apparatus, a movable liquid dispensing means movable to vary the static head and thus the amount of liquid discharging therefrom, said dispensing means having a restricted outlet, means for maintaining a supply of the liquid to said dispensing means, a reaction chamber for receiving said liquid, means for introducing in constant volume flow a second liquid into said chamber, a pair of electrodes arranged in the chamber to form with the liquid therein a galvanic cell, means including means responsive to variation in the output current of said cell for moving said dispensing means, and means for measuring the rate of flow of the liquid discharging from said dispensing means.

8. In a titration apparatus, a movable liquid dispensing means movable to vary the static head and thus the amount of liquid discharging therefrom, means including a constant level device for supplying the liquid to said dispensing means, a reaction chamber for receiving said liquid, means for introducing in constant volume flow a second liquid into said chamber, means including means associated with said chamber and responsive to changes in the physico-chemical properties of the solution created by the mixture of said first and second liquids for moving said dispensing means, and means for measuring the rate of flow of the liquid discharging from said dispensing means.

9. In a titration apparatus, a pivotally mounted shaft, means for turning said shaft, a movable dispensing tube fixed radially on said shaft for movement therewith to various angular positions, means connected to said tube for supplying a liquid thereto and positioned to give a constant head at the point of said connection, the angular position of said tube regulating the static head of said liquid and thus the rate of flow of said liquid through said tube, a chamber for holding liquid, means for conducting liquid discharging from the dispensing tube at angularly adjusted positions to the chamber, means for introducing into said chamber a constant volume flow of a second liquid, a pair of electrodes arranged in the chamber to form with the liquid therein a galvanic cell, and means responsible to the output current of said cell for actuating said means for turning said shaft to vary the angular position of said tube.

10. In a titration apparatus, a pivotally mounted shaft, a movable dispensing tube fixed radially on said shaft for movement therewith to various angular positions, means connected to said tube for supplying a liquid thereto and positioned to give a constant head at the point of said connection, the angular position of said tube regulating the static head of said liquid and thus the rate of flow of said liquid through said tube, a chamber for holding liquid, means for conducting liquid discharging from the dispensing tube at angularly adjusted positions to the chamber, means for introducing into said chamber a constant volume flow of a second liquid, a pair of electrodes arranged in the chamber to form with the liquid therein a galvanic cell, a reversible motor drivably connected to said shaft, normally open circuits for supplying electrical energy to said motor, and means selectively responsive to the output current of said cell for closing one of said circuits to energize the motor to turn the shaft to vary the angular position of said tube.

11. In a titration apparatus, a pivotally mounted shaft, a movable dispensing tube fixed radially on said shaft for movement therewith to various angular positions, means connected to said tube for supplying a liquid thereto and positioned to give a constant head at the point of said connection, the angular position of said tube regulating the static head of said liquid and thus the rate of flow of said liquid through said tube, a chamber for holding liquid, means for conducting liquid discharging from the dispensing tube at angularly adjusted positions to the chamber, means for introducing into said chamber a constant volume flow of a second liquid, a pair of electrodes arranged in the chamber to form with the liquid therein a galvanic cell, a reversible motor drivably connected to said shaft, normally open circuits for supplying electrical energy to said motor, a prime relay for closing each of said circuits, relay means for operating each of said prime relays, and means responsive to the output current of said cell for selectively operating the relay means to operate one of the prime relays to close a circuit to energize the motor to turn the shaft to vary the angular position of said tube.

12. In a titrating apparatus, a pivotally mounted shaft, means for turning said shaft, a movable dispensing tube fixed radially in said shaft for movement therewith to various angular positions, a constant level reservoir for holding a liquid, a conduit for connecting the reservoir to the dispensing tube at a point removed from its free end, the angular position of said tube regulating the static head of said liquid and thus the rate of flow of said liquid through said tube, a chamber for holding liquid, means for conducting liquid discharging from the dispensing tube at various angular positions to the chamber, means for introducing in constant volume flow a second liquid into said chamber, a pair of electrodes arranged in the chamber to form with the liquid therein a galvanic cell, means controlled by the output current of said cell for actuating said means for turning said shaft to vary the angular position of said dispensing tube, and means for measuring the rate of flow of the liquid passing through said dispensing tube.

ERWIN E. MORSE.

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