United States Patent

Shirakawa et al.

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[54] TITRATION AUTOMATON

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Related U.S. Application Data

[63] Continuation-in-part of Ser. No. 654,452, July 19, 1967, abandoned.

[30] **Foreign Application Priority Data**

July 23, 1966 Japan.....41/48248

[52] **U.S. Cl.**.....**23/253 R,** 23/230 R, 204/195, 324/30

[51] **Int. Cl.**.....**B01k 3/00,** G01n 27/56, G01n 31/16

[58] **Field of Search**.....23/253, 253 A, 230, 230 A; 204/195 T, 225; 235/151.12; 222/52, 63, 309, 384, 420; 141/83, 130; 324/30

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[57] **ABSTRACT**

An automatically operated titration system, or titration automaton, is provided for performing neutralization titrations, oxidation or reduction titrations, and for automatically recording the results thereof. Titration takes place in a rough stage followed by one or more progressively slower fine stages. A monitor is included to shut off the apparatus if any of the automated operations exceeds its preset maximum time.

7 Claims, 12 Drawing Figures

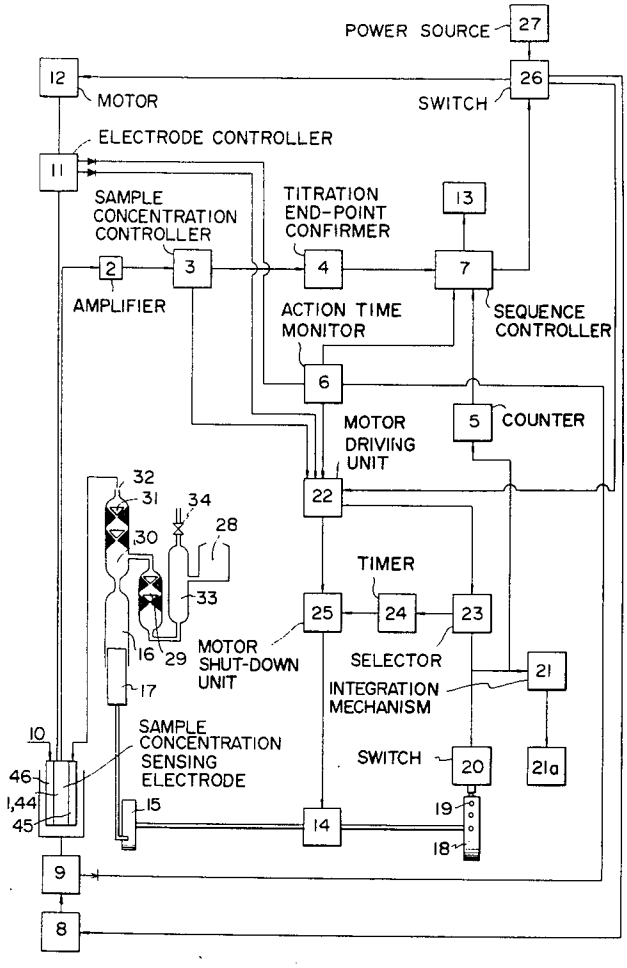
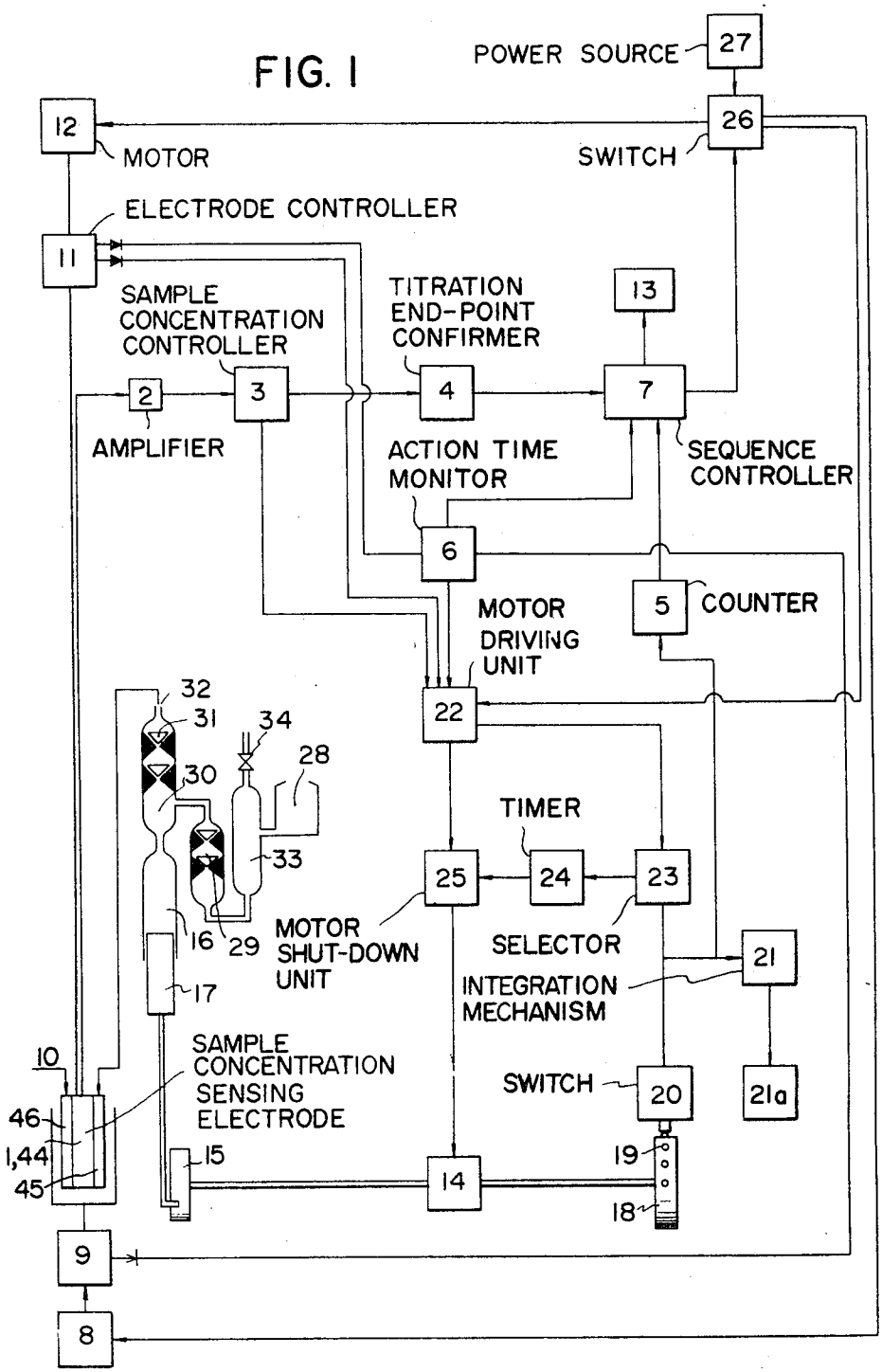


FIG. 1



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FIG. 2

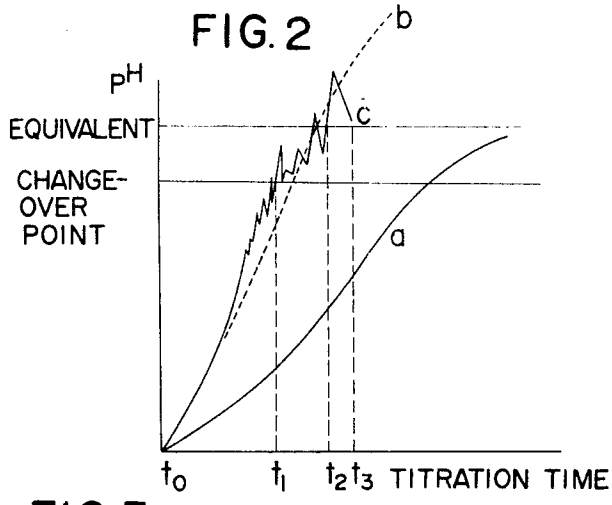


FIG. 8(a)

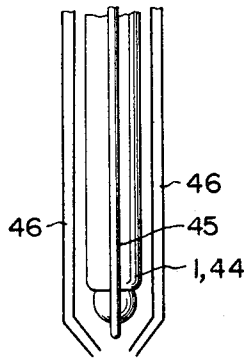


FIG. 3

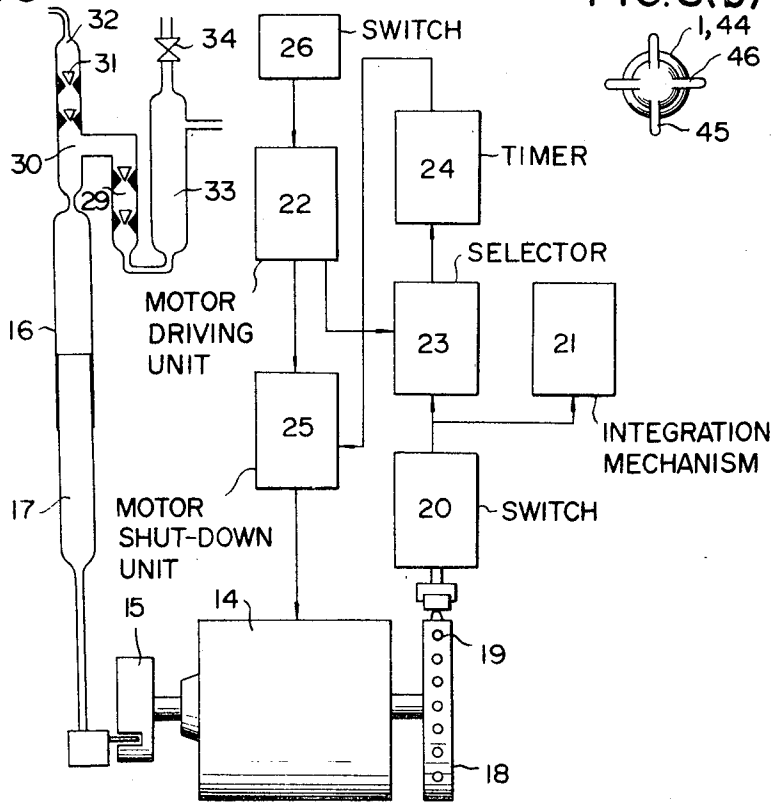


FIG. 8(b)

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FIG. 4(a) FIG. 4(b)

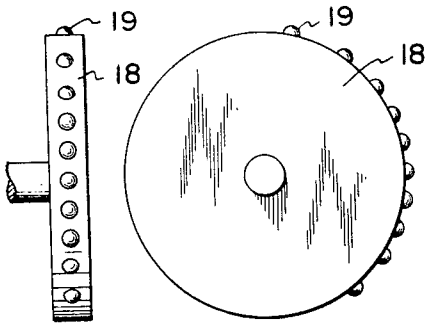


FIG. 5

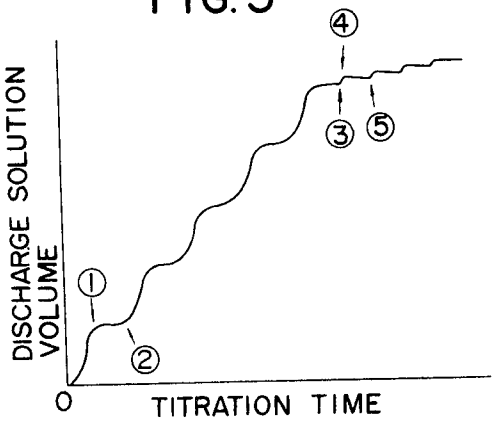


FIG. 6

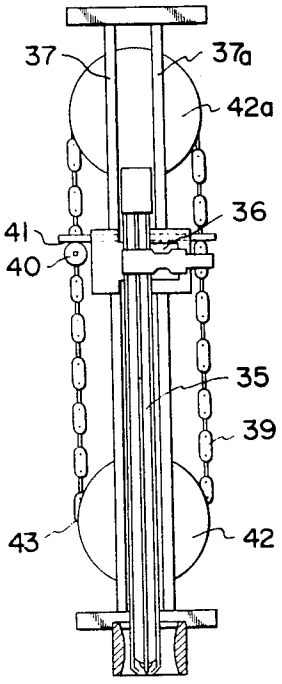
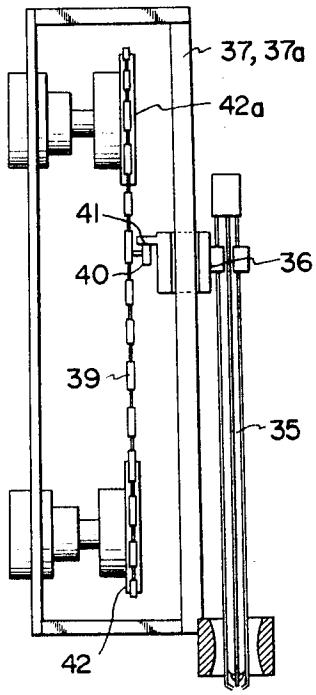


FIG. 7



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FIG. 9

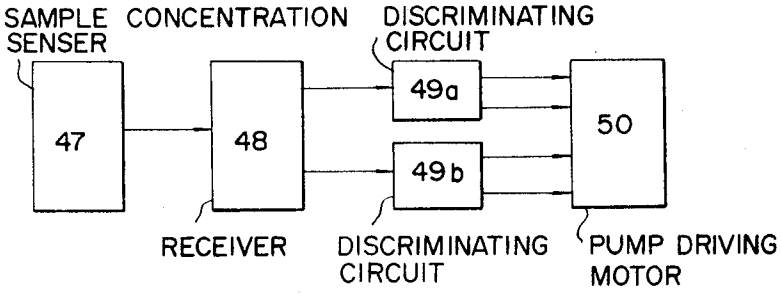
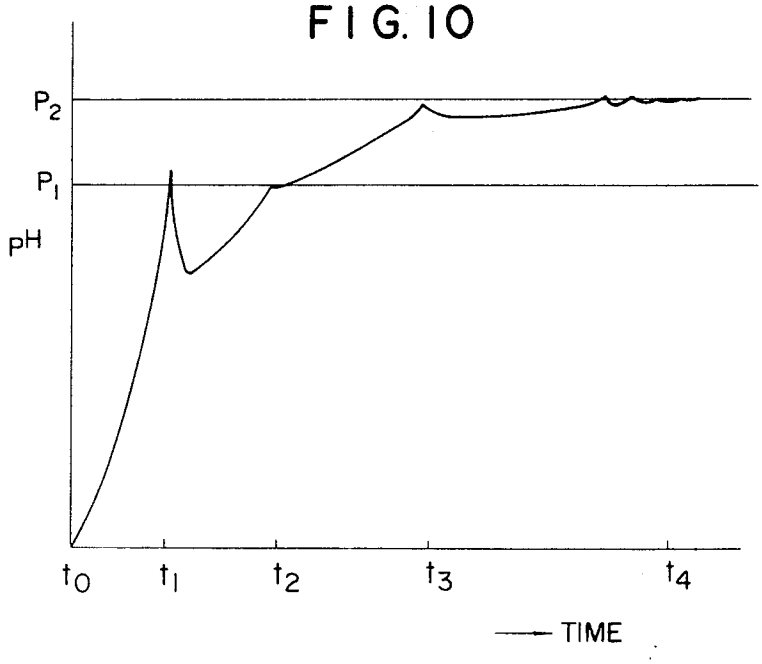


FIG. 10



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TITRATION AUTOMATON

CROSS-REFERENCES TO RELATED APPLICATIONS

This invention is a continuation-in-part of our pending application Ser. No. 654,452, filed on July 19, 1967, and now abandoned.

BACKGROUND OF THE INVENTION

The field of the invention comprises automatically operated titration systems. Conventional automatic titration apparatus employs continuous dripping of standard solution, thus presenting a danger of overtitration, and requiring a sufficiently reduced titration speed to take into account the effects of agitation and delay of response of the sample concentration sensor. Hence its titration efficiency was low.

More particularly, in conventional titration apparatus: (a) standard solution is supplied in a cylinder so finished as to have a volume in excess of the volume of standard solution required to titrate at least one sample, and to have a uniform cross section within a given range of error, and the solution is discharged by means of a piston operating at a constant speed continuously; (b) the changeover from rough titration used in the initial titration period to fine titration near the titration end point is performed by changing from high to low the revolution speed of the motor moving the piston; (c) the replenishment of the standard solution in the cylinder is performed by operating the valves of a T-joint connected to the cylinder and then by moving the piston in a direction opposite to that for the titration; (d) the amount of titration is indicated by the displacement of the piston or by the revolution factor of the motor.

These characteristics of the conventional apparatus suffer from the following shortcomings: (a) It is mandatory that the cylinder interior be finished with a high precision within a fixed range of errors to attain a uniform cross section and the piston also needs to be finished with high precision so that it will slide smoothly within the cylinder, and in addition, so that the fluid will not leak out, thus making the structure highly expensive. Further, since these parts need to be made particularly for the given titration apparatus, such expensive spare parts need always to be available for emergencies. In case the spare parts are unavailable, the entire apparatus has to be held on a downtime status for a long period of time. Furthermore, although the cylinder and piston might have been finished with high precision, the cross sections of the cylinder head and the cylinder tail are more apt to differ slightly, wherefore, errors in dripping are most likely unavoidable. (b) In performing a fine titration by lowering the displacement speed of the piston operating in a cylinder of a volume equal to several times the predicted titration volume, there remains a limit to the ability to perfectly eliminate over titration. Especially in the case of a sample of lesser pH buffer coefficient, such as a sample for microbiological titration, this step is likely to result in an overtitration in a neutralization titration. Furthermore, in order to minimize overtitration owing the delays stemming from the concentration detector system or from agitation, the dripping speed must be lowered; however, since there exists a certain limit to the adjustable range of dripping speed, the method itself is bound to suffer with respect to titration precision. (c) The time expended in the replenishment of standard solution in the cylinder does not contribute to the titration work itself and is thus a waste, and consequently the titration efficiency is reduced. In addition, frequent usage of the valves to feed standard solution may ultimately lead to failures, and lengthy usage may cause leakages. Also, referring to the fact that since the revolution speed of the motor is not sufficiently variable, the motor speed is normally set high so as to increase the titration efficiency, but only at the cost of the ability to perform a fine titration. And where a conventional sample concentration sensing electrode controller was used, it was found impossible to operate it at a high speed because of its particular structure; thus it constituted a hindrance to the promotion of titration efficiency and some times led to electrode damage.

The titration apparatus of this invention is designed to eliminate the described shortcomings inherent in conventional apparatus.

SUMMARY OF THE INVENTION

A titration apparatus is provided which employs two-stage titration, rough and fine. In the rough titration state, a signal is generated by a sample concentration sensor electrode and is transmitted to a sample concentration controller; the latter transmits the signal to a motor driving unit which in turn controls the introduction of standard titrating solution to the sample being titrated. As the operation reaches a rough-to-fine titration conversion point, the generated signal influences the motor driving unit to slow down the rate of introduction of standard solution, and thus the fine titration stage is reached, which continues to end point, at which point the said controller signals a titration end point confirmer, and the latter signals a sequence controller. The sequence controller provides for stopping introduction of standard solution, for moving the electrode out of the way, for moving the sample out of the way and transporting a succeeding sample into position, and for moving the electrode back into position. An action time monitor regulates the sequence controller in the performance of the foregoing functions by having preset therein (in the monitor) values of maximum times for carrying out these functions; thus, if one of these maximum times is exceeded, the monitor, by issuing appropriate signals, i.e., to the sequence controller and to the motor driving unit, is able to bring operation of the entire apparatus to a halt. Also, a counter regulates the volume of solution introduced to the sample, and, upon the appearance of an excess volume, signals the sequence controller to bring to the operation to a halt. The action time monitor and the counter comprise a fault detection system.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention is illustrated in the accompanying drawings, in which:

FIG. 1 is an embodiment of this invention shown in block diagram.

FIG. 2 is the characteristic curve indicating the relationship of the titration time against detected pH varation of the sample.

FIG. 3 is a block diagram of the standard solution dripper.

FIG. 4 shows a countercam used in the standard solution dripper, (a) front view, (b) side view.

FIG. 5 shows the characteristic curve of the relationship of titration time against standard solution discharge of the dripper shown in FIG. 3.

FIG. 6 shows front view of a sample concentration sensor electrode control.

FIG. 7 is a profile view of the unit shown in FIG. 6.

FIG. 8 shows the structure of electrode tip, (a) profile view, (b) bottom view.

FIG. 9 shows an improved embodiment of sample concentration sensor and control.

FIG. 10 shows the equivalence control characteristic as applied to the apparatus shown in FIG. 8.

For the sake of convenience of explanation, at first the structure and operation of the titration automaton by this invention as a whole shall be explained with recourse to FIG. 1 and FIG. 2. As the sample vessel is carried to the designated position by the sample transporter 9 which is driven by motor 8, motor 12 drives electrode controller 11, and the electrode descends and plunges into the sample. As the electrode descends down to the designated position, electrode controller 11 issues a signal to motor driving unit 22, as a consequence motor 14 rotates to turn cam 15, in turn piston 17 of the cylinder assumes reciprocating motion. Because of this, as shall be described later, as effected by the standard solution dripper, standard solution limited to a predetermined amount per drop is dropped in the sample intermittently, dropped especially in the vicinity of sample concentration sensing elec-

trode 1. The sample and the standard solution dropped into it are agitated by means of air passing through (Air passing is desirable especially when the vessel is small; in FIG. 1 the numeral 10 indicates air tube.) so as to make the concentration uniform.

The signal issued from sample concentration sensing electrode 1 is amplified by amplifier 2, and is transmitted to a signal-receiving means in the form of sample concentration controller 3. Sample concentration controller 3, upon reaching a value preset in rough-fine titration changeover, in turn issues a signal to motor driving unit 22, and then motor 14 shifts over from rough titration speed to fine titration speed to initiate a fine titration. In FIG. 2, t_1 corresponds to the time position of this event. As the sample concentration controller 3 receives a signal informing that the fine titration has progressed and the sample concentration has reached equivalent, or titration end point sample concentration controller 3 transfers the signal to titration end point confirmer 4. In FIG. 2, t_2 corresponds to the time position of this event.

Moreover, a mechanical signal is originated by projection 19 of countercam 18 coupled to the axle of motor 14 and is converted to an electrical pulse by which 20; the pulse is transmitted to integrator 21, then recorded in recorder 21*a*, and at the same time the pulse is transmitted to selector 23. Selector 23 operates only when the output voltage of motor driving unit 22 has dropped low. Upon entering fine titration time stage, the rotation speed of motor 14 drops, and said pulse is simultaneously transmitted to timer 24. Timer 24, as it receives the pulses from selector 23, sends said pulses to motor shutdown unit 25 for the duration of time preset; this will cut off temporarily the input circuit of motor 14 for the said duration of time, thus shutting down motor 14 temporarily; subsequently, motor 14 is operated intermittently, by means of which the overtitration due to overrotation of the motor is prevented.

In case the signal of the equivalent received from sample concentration controller 3 continues in confirmer 4 for a longer time than the fixed duration of time preset (in other words in case t_3-t_2 in FIG. 2 is longer than the time preset), that is, in case a titration is completed, a signal is issued by said confirmer 4 to sequence control 7, and in turn a signal is sent to the standard solution dripper via switch 26 and via motor driving unit 22, and also to the driving unit 12 for the electrode controller 11, and to sample transporter 9 via motor 8. These actions will at once stop the standard solution dripper and also raise the electrode, and the finished sample vessel is replaced by the next sample vessel.

After this the above procedure is repeated.

The functions of each of said units between the completion of titration of one sample and commencement of the next titration are monitored by action time monitor 6. Preset in this monitor 6 are the times corresponding to the maximum values of electrode motion time, the time counted from the electrode lowering to commencement of operation of standard solution dripper, and the action time of the sample transporter. When one of these action times has exceeded the assigned maximum value, the monitor issues a signal to sequence controller 7 and to motor driving unit 22, and sequence controller 7 works switch 26. As a result, the operation of the entire system comes to a halt.

The standard solution dripper in the titration automaton of this invention is of a high titration precision, and its titration efficiency is also high. This standard solution dripper comprises the following components:

a. A pump mechanism, or reciprocating pump means, in which piston 17 is caused to make sliding reciprocations in cylinder 16 by the rotation of piston driving cam 15 which is coupled to said piston and to motor 14. A part of the standard solution required for the titration is taken in and discharged in one reciprocation of the piston.

b. A counterintegrator mechanism, or pulse-producing means, comprising switch 20, which generates an electrical pulse when it comes in contact with a projection 19 on the periphery of circular counter cam 18 rotating in response to the rotation of motor 14; integrator 21, which integrates pulses from the switch; and recorder 21*a*.

c. Motor driving control mechanism comprising selector 23, which transmits to timer 24 the pulse from switch 20 which acts to originate a pulse when the output voltage of motor driving unit 22 has changed from high to low; said timer 24, which transmits the pulse to stop the motor 14 for the limited duration of time preset by the signal from said selector 23; and motor shutdown unit 25, which inactivates, upon receiving signals from timer 24, the circuit between motor driving unit 22 and motor 14 on arrival of each signal for the duration of time preset in the timer 24.

d. Motor driving unit 22, whose input side is connected to power source 27 via switch 26, and whose output side comprises a control mechanism which is capable of varying rotation speed of motor 14 when a signal is received from sample concentration controller 3 announcing that the value detected by the detector in the titration system has come to agree with the preset value; said output side is connected to motor 14 via motor shutdown unit 25.

The motor shutdown unit 25 and the motor 14 comprises a means for regulating the speed of the pump, and as is apparent, such means is controlled by the motor driving unit 22.

The piston driving cam 15 is normally an eccentric cam; it controls flow of standard solution into and out from the cylinder 16 under rough titration conditions; and it transmits the driving force of motor 14 to piston 17 in cylinder 16 when discharging standard solution in a duration of fine titration. AT 28 is a standard solution tank; 29 is a check valve in the suction side which opens to suck standard solution into chamber 29*a* and cylinder 16, and closes when solution is discharged therefrom; 30 is a three-way channel in the discharge outlet of the cylinder 16; 31 is a check valve at the discharge side which opens when the cylinder is discharging and closes during the suction period; and 32 is a discharge line leading into the titration system. It may be seen that the cylinder 16 and piston 17 comprises a syringe which injects measured amounts of standard solution into the titration sample.

As cam 15 turns by the aid of motor 14, piston 17 reciprocates, and the standard solution in standard solution tank 28 is fed into the titration system through discharge line 32.

Continuation of titration for long hours generates bubbles in standard solution tank 28 and these bubbles may get confined in the syringe and might cause the titration values to vary. For this reason a bubble remover 33 may be installed between tank 28 and check valve 29. This means that if any bubbles generated within the standard solution tank are attracted toward the syringe, as they reach bubble remover 33 they will be interrupted by the void above, with the result that in no case will bubbles travel any further. When remover 33 is filled with bubbles, the cock 34 is opened to release the vapor.

A suitable volume of the syringe would be that wherein the discharge of one stroke of piston 17 is to be of the order of several parts to several tenths of the standard solution required for the titration of one sample. This proportionality makes for higher titration precision, reduction of cost of parts, and ease of part replacement.

The rough titration is performed with a volume equal to several parts to several tenths of the fillings of syringe volume, and fine titration is performed with a drip volume still less, of the order of, say, several tenths of the volume of the syringe, as shall be mentioned later, therefore, since the drip fluid per charge would be extremely minute in the case of fine titration, it becomes much easier to prevent over titration. Normally, an injection syringe of the order of 0.2 milliter effective volume is used. Moreover, the syringe could be of smaller size, and thus the process precision can be elevated. Consequently titration precision will be raised.

Because smaller size syringes are acceptable, conventional commercial injection syringes made of glass, or plastic, which

are acid- and alkali-resistant materials, such as a commercial syringe for tuberculin injection, can be used for the purpose. For this reason there is no need of retaining expensive syringes as spare parts, as has been done in the case of conventional apparatus, and in a case of breakage, it is only necessary to replace the syringe with a commercial syringe, thus making the replacement less costly.

Countercam **18** is a means to count the number of strokes of piston **17** executed in the course of discharge in a rough titration stage, and extent of movement of the piston in the course of discharge in a fine titration stage, and rotates simultaneously with cam **15**, both cams being driven by motor **14**. Cam **18** consists of a circular disk having its revolving axle at its center and having a plurality of projections **19** provided along one-half (FIGS. **4**(a) and **4**(b)) of the periphery of the circular disk. The number of the projections **19** is randomly determined by the magnitude of the discharge volume per drip in a given fine titration stage, in other words, determined by what fraction of the drip volume per reciprocation of the piston shall be set as the titration precision. For the determination of the position of each projection, the diameter of the circular disk is sectioned equally a number of times equal to said randomly determined number, straight lines are drawn through these sectioned points and perpendicular to the diameter, and the points of intersection of each of these lines with the periphery of the circular disk, covering one-half of the periphery, give the position of the projection points. FIG. **4** shows the case for 10 projections. The angular displacement, due to rotation of cam **18**, of a projection **19** is transmitted directly or indirectly to the contactor of switch **20**, and in the stage where no projection is facing switch **20**, i.e., between projections, no signal whatsoever is supplied to switch **20**. Moreover, piston driving cam **15**, which is rotating coincidentally with countercam **18**, is mounted in such a way that piston **17** goes into a suction process in this particular stage of time. By designing the system to this effect, the response delay and agitation delay developed in the titration system in the preceding discharge process can be nullified during the suction of fresh standard solution for the syringe. For this reason, the time expended solely for the replenishment of standard solution in conventional automatic titration apparatus can be utilized effectively for delay nullification by this system, thus making possible a great enchancement of speed of sample titration.

Switch **20** is a means to convert the mechanical signal originated by projections **19** on countercam **18** into electrical pulses, and integrator **21** receives the electrical pulses sent from switch **20** and is capable of adding and storing a number of the pulses. This integrator **21** could be of an optional system, but must be able to respond to pulses promptly and accurately, to store the added results, and also to transmit the added results to recorder **21***a* connected to integrator **21** when necessary. This integrator recorder is of digital type, and consequently the records of the titration values are indicated in digital form. Of course numeral indication of records is possible by using a record printer.

The pulse from switch **20** is transmitted to integrator **21** and simultaneously to selector **23**. This circuit operates when the output voltage of motor driving unit **22** becomes low. In other words, as the process is moved to the fine titration stage, the revolution of motor **14** drops; at the same time, upon receiving pulses from selector **23**, the timer **24**, for this normally a timing switch is used, transmits pulses to motor shutdown unit **25** for a limited duration of time preset. This set value of time is determined by the minimum time required by the standard solution sensor to become able to correctly respond to the condition after standard solution is dripped in the sample and mixed well to establish uniformity in the solution, and by taking into account of various factors, namely response characteristic of sensor, buffer coefficient, viscosity, density of sample, and agitation method employed. For an instance in the case of a sample requiring a microbiological titration method, this set value of time is of the order of 2 sec. The timer **24** could well be of electrical, mechanical or electromechanical means.

Motor shutdown unit **25** is positioned between motor driving unit **22** and motor **14**, and upon receiving a signal from timer **24**, shuts off the input circuit of motor **14** for the duration of time set in timer **24**, and normally a magnetic relay is employed for it. In this manner by providing a timer, errors of overtitration due to the response delay of the sensor disposed in the mixture of standard solution and sample can be prevented.

Motor driving unit **22** is a control unit connected to power source **27** via switch **26**, and when a signal is received from sample concentration controller **3** informing that concentration of the sample in the titration system has come to the point preset, unit **22** reduces the speed of motor **14**.

Referring to FIG. **5**, it is a characteristic curve of this titration apparatus, wherein standard solution discharge volume at the time of titration is plotted as ordinate and titration time as abscissa. In the figure, **0** is the initial point of rough titration, **1** is the point at which the first discharge of standard solution was completed, and **2** indicates the point at which the next discharge was started. The interval between **1** and **2** is a no discharge stage, and in this interval a suction of standard solution is performed, at the same time sensor response delay and agitation delay are compensated. Further, after discharges and suctions are repeated, and as the sample concentration reaches the point of rough-fine titration changeover, the voltage of the motor driving unit drops, in turn the speed of motor **14** also drops, and then a fine titration starts. In other words, this will bring the process up to the point **3** of the curve, and after a fine titration the process comes to quiescence at point **4**. Standard solution volume per discharge in the stage of fine titration is to be several parts to several tenths of the volume assigned to countercam **18** for rough titration. In other words, several parts to several tenths of the length obtained by projecting the incline **0–1** as ordinate corresponds to that of **3–4**. The stage from **4** to **5** is a quiescent stage, and the stage is utilized to compensate various delays which cause overtitrations.

Since the motor **14** rotates continuously, countercam **18** also rotates continuously, the number of its rotations is integrated by integrator **21** via switch **20**, and is recorded in recorder **21***a*. The counterpulse from switch **20** is sent also to selector **23**, but it will not act while the output voltage of motor driving unit **22** is high, that is, during the rough titration stage. As the sample reaches the rough-fine titration changeover point, output voltage of motor driving unit **22** drops, the speed of motor **14** drops, at the same time selector **23** transmits the pulse from switch **20** to timer **24**. This pulse is then transmitted, for the duration of time preset in timer **24**, to motor shutdown unit **25**, this will temporarily cut off the motor input circuit, and in turn will shut down motor **14** for the same temporary period, resulting overall in preventing incidences of over titrations. As the said preset time elapses, motor **14** will again rotate and titration starts, however it will again stop with the arrival of the next pulse from switch **20**. Subsequently, identical actions are repeated. As the sample reaches equivalence, as will be mentioned later, the output of motor driving unit **22** is cut off by the signal from sample concentration controller **3**, motor **14** stops, and this will complete one round of titration.

The electrode in the electrode controller **11** is retained firmly by an electrode holder which is movable up and down in a guide structure paralleling the electrode. Two rotatable structures are disposed on the guide structure at upper and lower points and these structures are linked with a rotary chain. On this rotary system is a supporter for the electrode holder. The system is capable of rising and descending by means of rotation of said rotatable structures.

FIG. **6** is a front view of one embodiment of this system, and FIG. **7** is a side view thereof. By means of electrode holder **36**, electrode **35** is held with a force fit at a random point on the electrode but preferably near its upper end. The holder is slidably coupled to guide ways **37**, **37***a* disposed in parallel

with electrode 35. Other guide ways are useful, such as one with guide slots or a structure in rail form, provided they have the capability to move the electrode holder 36 vertically in an up-and-down direction, and provided they are acceptable to the structure of holder 36, for example, with holes, projections, rollers, or wheels on it. At 39 is a ring belt, and at a random position on this belt a pin 40 is fixed as supporter to support electrode holder 36. The ring belt could be either steel strip, chain or an adjustable belt. The pin or supporter 40 consists of a projection, roller, wheel or other device in direct contact with contact piece 41 of electrode holder 36. At 42 and 42*a* are gears working as rotatable structures positioned at head and foot of the system, one gear is for chain drive and the other is for chain guide. These rotatable structures could be any suitable device provided it is acceptable to the structure of the ring belt in use. With reference to FIG. 6, the gears 42 and 42*a* are driven by a motor, not shown, which may drive chain 39 counterclockwise so that the left side of the chain moves downward, and pin 40 will naturally descend. Consequently, electrode holder 36, supported by the pin in contact at contact piece 41, and the electrode both descend by their own weights, as the pin 40 descends, with the same speed as that of the chain. As the pin reaches the point 43, where gear 42 is disposed, pin 40, still in contact with the lower face of contact piece 41, moves to the right with the chain movement, and then moves upwardly. As the pin rises, electrode holder 36 is forced to move upward and as a result, electrode 35 fixed to it is also caused to rise. As seen in the drawings, the time during which the pin 40 descends to its lowest point is the same as the time during which the electrode 35 descends to its lowest point; however, this operation may be modified as by disposing a projection at a suitable position in a lower portion of guide way 37 or 37*a*, then, as the electrode holder 36 descends to that position, holder 36 separates from the pin 40 and will be supported by said projection; pin 40 on the other hand separates from contact piece 41, reaches the bottom of the system, changes to upward motion, and comes in contact with the other end of contact piece 41 of electrode holder 36. Thus, the electrode can be made to stay at its lowest position for a fixed period of time. Moreover, when using the apparatus, by separating the pin 40 fixed on ring belt 39 and by disposing contactor at a suitable position to act at a lower or higher position of the guide way, the rotation speed of the gear rotated by the motor can be varied so as to make the rising speed of the electrode higher than its descending speed, a technique which is effective in expediting automatic titration.

In the case of this electrode controller, the electrode is not forced but descends by its own weight. Now, suppose the sample transporter 9 were not synchronized with the electrode controller, and the sensor disposed at the tip of the electrode has failed to assume proper position in a sample, thus resulting in a fault causing the electrode to ride on the upper part of the sample vessel; even in this case, since the electrode is not influenced by any other force except its own weight, it will come to a halt at the position of its contact with the vessel. As a consequence, that part of the electrode sensor more apt to get broken can be saved from damage.

The control system of the apparatus of the invention comprises mainly the sample concentration sensor and controller, fault detector, and sequence controller.

The sample concentration sensor and controller is composed of two units, namely, sample concentration controller 3, which receives the amplified signal from sample concentration sensor equipped with concentration-sensing electrode 1 and issues a signal when the sample concentration has reached the concentration preset, and the titration end point confirmer 4, which receives from said controller 3 the signal informing that the process has reached equivalent point.

The fault detector is composed of two units, namely, counter 5, which issues a signal to sequence controller 7, which will be described later, when standard solution drip volume has exceeded the preset value, and action time monitor 6, which issues a signal to sequence controller 7 when one of various times, namely, the time covered from electrode descent to the action of standard solution dripper, or electrode motion time, or sample transporter action time, has exceeded the time preset.

Sequence controller 7 receives signals from said titration end point confirmer 4, counter 5, or action time controller 6, and, in response to a given signal, operates or stops the automatic transporter 9 or the standard solution dripper, whichever the case may be in compliance with the programs preset.

Now, referring to FIG. 1, as the sample vessel is moved to the designated position by the actions of motor 8 and the sample transporter 9, the motor 12 acts on electrode controller 11, and the electrode descends and submerges in the sample. Next, the standard solution dripper is operative to drip standard solution in the sample with a fixed volume per drop, intermittently but instantly, especially in the vicinity of sample concentration sensor of the electrode 1. On the other hand, sample and standard solution are agitated by means of air or by an agitator (in case the sample vessel is small, air agitation is especially desirable, and 10 in FIG. 1 shows the air tube).

The utilization of a dripper that drips a fixed volume per drip of standard solution intermittently but instantaneously in the vicinity of the sensor electrode is one of the marked features of the apparatus. In the case of conventional automatic titration apparatus, standard solution was dripped continuously, and therefore it was necessary to reduce the drip speed sufficiently to cover the agitation lag and response delay of the sample concentration sensor, and in consequence, the titration process capability was bound to be low. In accordance with this invention, by exaggerating temporarily the excess titration in the vicinity of the sensing electrode by dripping standard solution in the vicinity of the sensing electrode, it is possible to elevate the accuracy of prediction of the end point (the equivalent) or equivalent point of titration and to create an environment immune to overtitration, even if titration (rough titration) is conducted at a high speed up to the neighborhood of the equivalent. FIG. 2 is a graph to explain this principle as applied to acid-alkali titration.

In the case of conventional apparatus, standard solution is dripped continuously, and in the result, under its best titration condition, the sensed pH varies with respect to the progress of titration time as shown by the curve *a* of FIG. 2. In such a case, an enhancement of titration speed in order to elevate process efficiency will make the curve rise sharply, as shown by the curve *b*, and an overtitration will result, thus producing a titration failure. According to the invention, in the initial period of titration the difference between pH in the vicinity of the sensing electrode immediately after a dripping, and pH after agitation is applied, is not so large; however, as the process progresses with intermittent drippings and as it reaches the stage near to the equivalent, the pH, right after dripping, in the vicinity of sensing electrode temporarily rises abruptly, and its tendency to abruptly drop by agitation becomes more pronounced. Consequently, the curve of pH variation sensed becomes as shown by curve *c*. As is evident from FIG. 2, in accordance with this method, even if the titration speed is taken to be considerably high in the initial period of titration, a solution whose concentration is close to that of standard solution will always reside in the vicinity of the sensing electrode; hence, the concentration detected by the sensor is always closer to that of the equivalent than the concentration of the sample after agitation. Therefore, even though it is temporarily detected as if it has passed the equivalence after a speedy titration, the actual titration can be held not to pass the equivalent after agitation. In other words, there exists no danger of overtitration, wherefore, it is possible to drip standard solution rapidly even until close to the equivalent.

Signals of the changes of sample concentration at the vicinity of the sensing electrode are amplified by amplifier 2 and transmitted to sample concentration controller 3. Preset in this controller (normally a two-contactor electrometer is employed) are the rough-fine titration changeover value and the

equivalent value. When the signal from amplifier 2 indicates that the concentration has reached the changeover value, the controller 3 issues a signal to motor driving unit 22 of standard solution dripper, and reduces the speed of motor 14, thus making the process to shift from rough to fine titration, and when the fine titration has progressed and the signal from amplifier 2 shows the equivalent value, the controller 3 transmits that signal to titration end point confirmer 4. This procedure shall be explained with recourse to FIG. 2. As the process progresses from its initial titration to to t_1, a signal, not instantaneous, informing that the concentration of sample has reached the changeover point, is received for the first time by sample concentration controller 3, a signal is sent to motor driving unit 22, and motor 14 reduces its speed, and after this a fine titration proceeds. When a signal, informing that fine titration has advanced and the sample has reached the equivalence, is received by sample concentration controller 3, the signal being received not temporarily but continuously, (that is, when t_2 is reached in FIG. 2), a signal is sent from sample concentration controller 3 to titration end point confirmer 4.

As for the titration end point confirmer 4, normally a long period relay timer is employed. When the signal of equivalent point from sample concentration controller 3 has continued longer than the fixed time preset in the said circuit 4 (that is when time t_3-t_2 in FIG. 2 is longer than the time preset in said circuit), signal is sent to sequence controller 7 to control the apparatus to proceed with the next action. This time set in the said circuit 4 can be selected to be sufficient, but may be short to compensate for various delays, such as response delay of sample concentration sensing electrode 1, delay of agitation of sample, response delay of sample concentration controller 3.

Enclosed in sequence controller 7 is a program that unfolds as follows: when a signal is received from said titration end point confirmer 4, signals are sent via switch 26 to the driving unit 22 for the standard solution dripper, to the electrode controller 11, and to the sample transporter 9, by which, at first, the standard solution dripper is caused to stop, next the electrode is caused to rise, and then the sample vessel is caused to move away to be replaced by another.

The actions which said units assume in the interval between the completion of titration of one sample and the initiation of the next titration are monitored by action time monitor 6. In other words, preset in this monitor 6 are maximum values of electrode travel time, the time from electrode descent to the starting action of the standard solution dripper, the worktime of the sample transporter; and the monitor is provided with an ability to issue a signal to sequence controller 7 in case any one of these action times has exceeded the corresponding value preset. When the sequence control 7 receives the described signal, it initiates an alarm if alarm 13 is present. Consequently, in case the electrode fails to travel for one reason or another, or in case of a fault in the standard solution dripper such as for example no dripping of standard solution due to a pipeline failure, or in case of some fault in the sample vessel exchange, the entire system immediately comes to halt, and by this means probable damages to the system can be held to a minimum level. When every action is performed correctly it will be so detected, and at the same time monitor 6 resets to zero point.

Counter 5, which restricts maximum drip volume, is connected to switch 20 of the standard solution dripper. This counter 5 is normally used to count drip volume; however, a maximum allowable standard solution dripping is set in it, and when drip volume has reached this maximum value, counter 5 will issue a signal to sequence controller 7 to bring the entire system to a halt. In case the total of drip volume per sample is less than the preset value, the counter resets to zero coincidentally with the completion of titration. The set value in counter 5 is higher than the titration volume of standard solution predicted to be needed for the sample to be titrated; in addition, it is less than the volume of the sample vessel used in the titration. The signal from counter 5 produces an effect exactly the same as the signal of said action time monitor 6. When a fault breaks out within the standard solution dripper, or a fault of electrode damage, or a fault in sample concentration control 3, or the drip volume is more than required and said set value in counter 5 is reached, then the entire system comes to a halt by the signal sent from counter 5, and in this manner, the continuation of wasting of standard solution is prevented.

Various forms of electrodes can be used easily in the titration automaton of the invention, depending on the requirement, such as an electrode with extremely small diameter, a compound electrode having a standard electrode and a measuring electrode enclosed in a single jacket, or a measuring electrode unit composed of a compound electrode, standard solution drip tube, and vapor transport tube for agitation, all consolidated in a unit.

Furthermore, as it is essential to drop standard solution in the vicinity of the electrode sensor intermittently but instantaneously, as described, therefore, as shown in FIGS. 8 (a) and (b), a compound electrode, consisting of sensing electrode 1 and a standard electrode 44, such as a hydrogen electrode or calomel electrode, may be used, and combined with them in said electrode structure is a standard solution discharge tube 45 and an air tube 46, and it is desirable to combine them all into as slender a tube as possible. In FIG. 8, the standard solution discharge tube 45 has its tip directed toward the electrode structure in such manner that standard solution can be sprayed onto the sensing electrode. The discharge tube and air tube are made of stainless steel or hard plastic slender tubes, and they also serve to protect the sensing electrode, which is more apt to get damaged.

In FIG. 9, an improved titration control system for the standard solution dripper is shown in block diagram. At 47 is a sample concentration sensor of a type like a pH meter, for example; at 48 is a receiver with contactors of a type like a two-setting meter relay (corresponding to sample concentration control in FIG. 1); at 49*a* and 49*b* are independent discriminating circuits; and at 50 is a driving motor for the standard solution dripper (corresponding to motor 14 in FIG. 1). A signal dependent upon the concentration of sample is transmitted from sample concentration sensor 47 to receiver 48. Preset in receiver 48 are two points, namely, titration end point corresponding to the equivalent, and a titration "fore end point" corresponding to a random pH of a process point lying in the course of titration leading to the titration end point, such random point being taken as close as possible to the titration end point.

The signal from sample concentration sensor 47 is divided into two parts in receiver 48, namely, (A) from titration initiation to titration "fore end point" and (B) after passage of titration "fore end point" to titration end point. Both of discriminating circuits 49*a* and 49*b* are so designed that when the value of the signal received from receiver 48 exceeds the random value preset in these discriminating circuits once and returns again, they generate a signal differing from the one which would be generated before the preset value was exceeded. Consequently, in the system in FIG. 9, the signal from sample concentration sensor 47 is divided into two in sequential order by both receiver 48 and discriminating circuits 49*a* and 49*b*, giving a total of four. The signals which were divided into four parts have the effect of varying the speed of pump-driving motor 50 in four steps in sequential order, the speed of motor in each step being preset so that the first step corresponds to rough titration, and the subsequent three steps correspond to fine titration.

FIG. 10 is one example (employing a two-setting meter relay) of an equivalence characteristic for a case in which this system is employed. In FIG. 10, ordinates indicate pH of the titration system examined, abscissas the time subsequent to titration initiation. P_1 is pH set value of titration "fore end point," that is rough-fine titration changeover, P_2 is pH set value for titration end point, that is the equivalent, t_o is titration initiation time, t_1, t_2, t_3 are times in the process leading up

to titration end point t_4, t_0—t_1 is rough titration period, t_1—t_2, t_2—t_3, t_3—t_4 correspond to first, second, third steps in the fine titration respectively.

As is evident from FIG. **10**, in this system after initiation of titration, the system is promptly shifted to the state of fine titration, and minute control of titration value is conducted in the course of fine titration to elevate the precision of the titration value. Especially, this system affords the desired result with a very simple mechanism.

In the embodiment above it is possible to divide the signal from sample concentration sensor **47** into three parts, rather than two, by cancelling the function of discriminating circuit **49***a*. In this case the system will be so set that rough titration is performed by the first signal and fine titration by the remaining two signals.

Further, it is possible to divide the signal into eight parts by adding to each of discriminating circuits **49***a* and **49***b* two new discriminating circuits **49***aa*, **49***ab*, **49***ba*, and **49***bb* (not shown); or else by cancelling any number of discriminating circuits off from these, the signal can be divided into any random number up to eight. Thus it is possible to make the fine titration in a plurality stages by varying the speed of pump-driving motor **50** in correspondence with the signals so divided.

Additionally, in a normal case, a satisfactory titration with high enough precision can be accomplished with discriminating circuits of the order of two in number, meaning three steps of fine titrations, without sacrificing the speed of titration. In this case, the drip speed in each step for example is as follows:

Step 1	Rough titration	10 ml./min.
Step 2	Fine titration 1	5 ml./min.
Step 3	Fine titration 2	2 ml./min.
Step 4	Fine titration 3	1 ml./min.

It will be obvious to those skilled in the art that various changes and modifications may be made in the invention without departing therefrom, and it is desired therefore, to cover in the appended claims all such changes and modifications as fall within the true spirit and scope of the invention.

We claim:

1. Titration apparatus comprising a sample vessel transporter for conveying sample vessels in succession into an operative position, a standard solution dripper for periodically discharging a predetermined quantity of standard solution into a sample vessel when in an operative position, an electrode movable into and out of a sample vessel when said sample vessel is in an operative position to sense a physical value of the solution, a fault detector comprising means for detecting the period of travel of the electrode when it is moved out of one sample vessel and into a subsequent sample vessel, means for detecting the period between the instant when the electrode has moved into said subsequent sample vessel and the instant the standard solution dripper has been actuated to discharge a standard solution into the vessel, means for detecting the time taken by the sample vessel transporter to convey one vessel from and a subsequent vessel into the operative position, comparison means for comparing the time detected by each detector means against corresponding preset values, and for providing an output if any of said preset values is exceeded, counting means for indicating the volume of standard solution which said standard solution dripper has discharged into a said vessel and a sequence controller for controlling the sample vessel transporter, said electrode, and the standard solution dripper in dependence upon the value sensed by said electrode, the count registered by said counting means and the output from said fault detector.

2. Apparatus according to claim **1** wherein said standard solution dripper comprises a piston and cylinder arrangement for discharging a predetermined volume of standard solution on each stroke that it makes, motor driven cam means for causing said piston to reciprocate within said cylinder, said apparatus further including a disc coupled to said cam means and bearing a plurality of projections around its periphery, sensing means for sensing the passage of projections therepast in response to rotation of said disc to provide output pulses representative of the quantity of solution discharged from said standard solution dripper, said output pulses being fed to said counting means, control means responsive to the output of the electrode to reduce the speed of the motor-driven cam means when the output indicates that a predetermined point in titration has been reached, timing means actuatable by said control means when said predetermined point in titration has been reached to periodically interrupt the motion of said motor-driven cam means, and stop means to halt said motor-driven cam means when the output from the electrode indicates the titration end point.

3. Apparatus according to claim **1** wherein an electrode holder is provided for supporting the electrode, guide means constrains said electrode holder for vertical movement, an endless belt is supported on said guide means, and an engagement member is rigid with said belt and arranged to engage said electrode holder, whereby on rotation of said belt in one sense said engagement member successively raises said electrode holder in said guide means and thereafter allows the electrode holder to descend under gravity.

4. Apparatus according to claim **2** including means for sensing an output from said electrode which is indicative of the titration end point and operative to inhibit the operation of said stop means if the indication of the titration end point is only of a transient nature.

5. Apparatus according to claim **4** wherein said control means is operative to reduce the speed of the motor-driven cam means progressively in steps in response to the electrode providing outputs indicative of different predetermined points in titration having been reached as the titration progresses.

6. Apparatus according to claim **1** wherein said standard solution dripper comprises a piston and cylinder arrangement for successively discharging a predetermined quantity of said standard solution into said vessel with each stroke of the piston, control means responsive to the electrode providing an output indicative that a predetermined point in the titration has been reached to cause intermittent motion of the piston with respect to the cylinder of the piston and cylinder arrangement and thereby cause periodic discharges, each being a fraction of said predetermined quantity, and sensing means responsive to the output of said electrode indicating that the end point of titration has been reached to sense whether or not said latter output is of a transient nature, said sensing means being operative if said latter output is not of a transient nature to prevent further discharge of standard solution into said sample vessel.

7. Apparatus according to claim **6** including an electrode controller for withdrawing said electrode from the sample vessel at the end of a titration, said electrode control means being thereafter operative to lower said electrode into a further sample vessel, said fault detector including means for determining the quantity of standard solution which has been discharged into a said vessel during a titration and operative to provide an output when said quantity exceeds a predetermined value.

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