

Nov. 1, 1960

C. D. ALWAY
COMPUTER

2,958,466

Filed May 6, 1957

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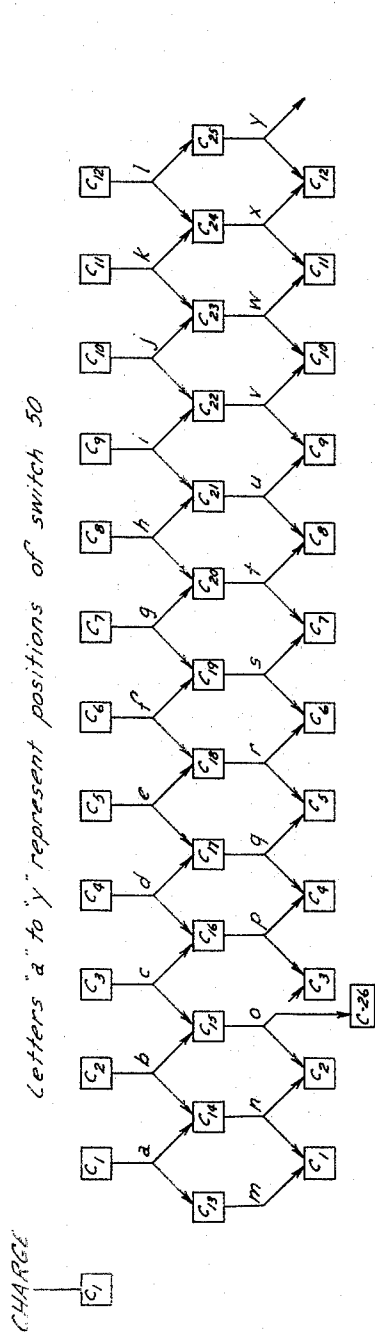


Fig. 2

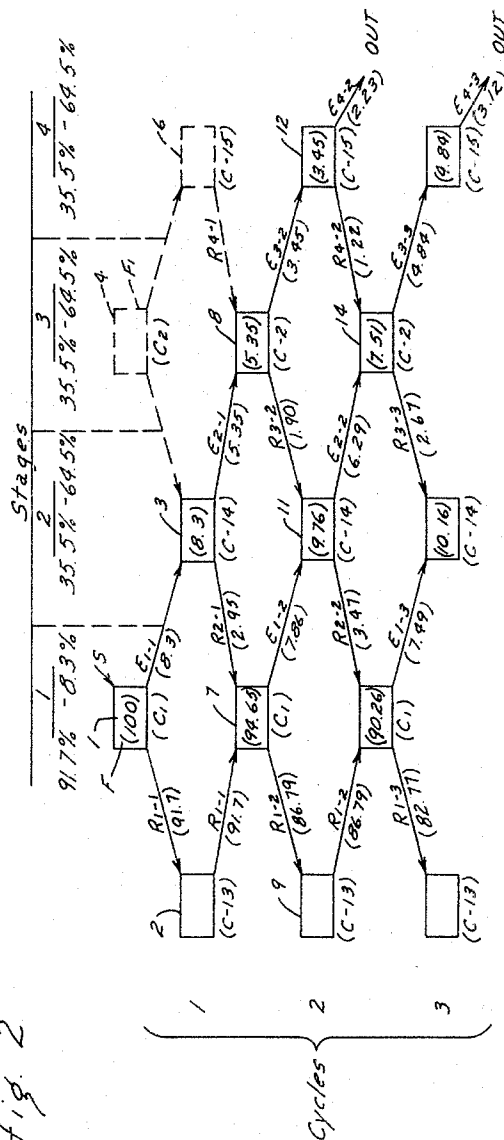


Fig. 1

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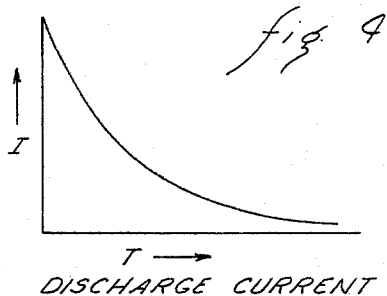
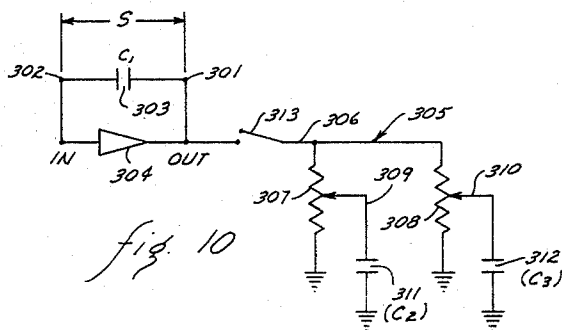
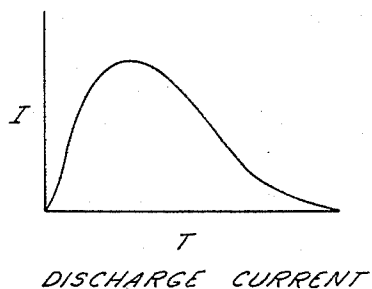
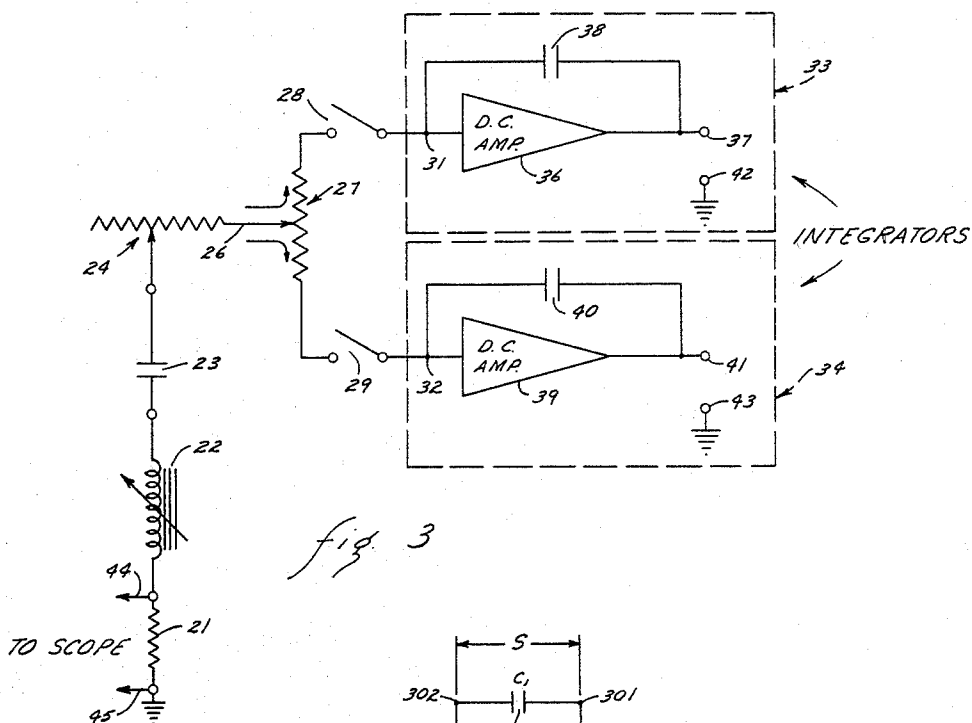


fig. 5

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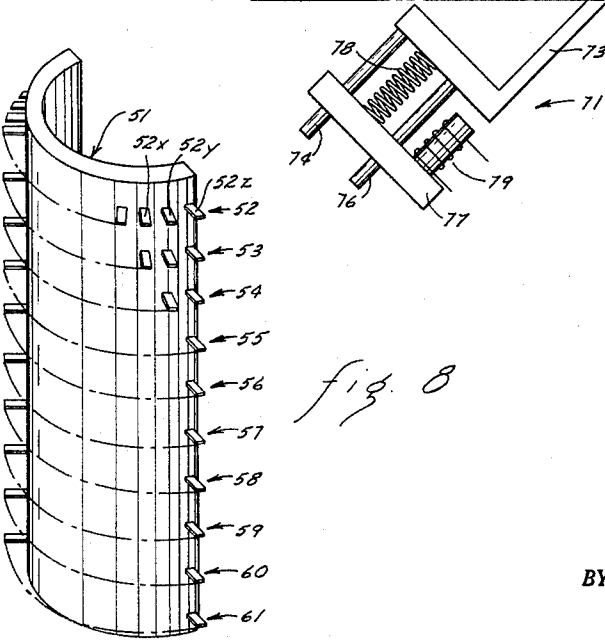
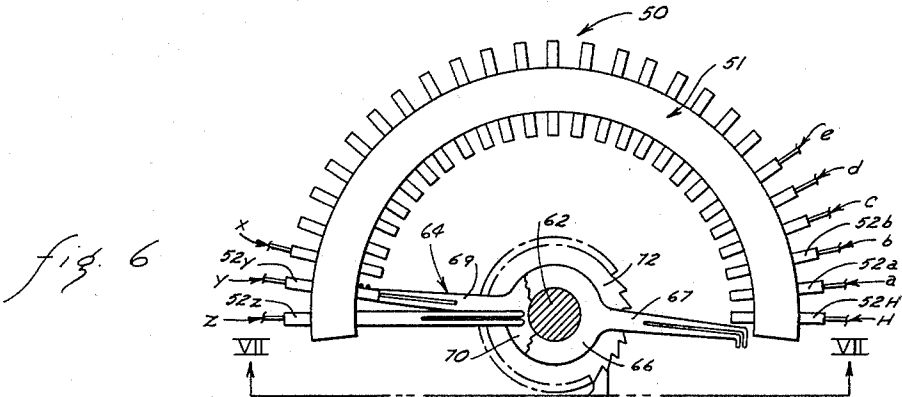
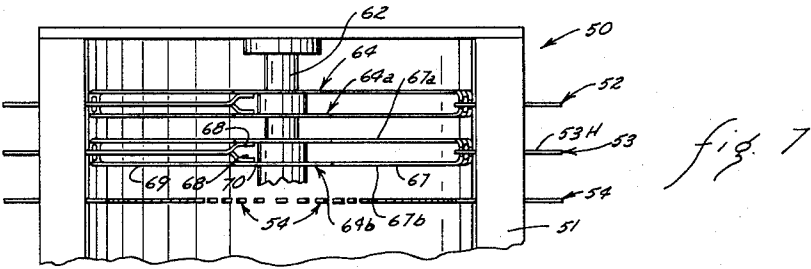
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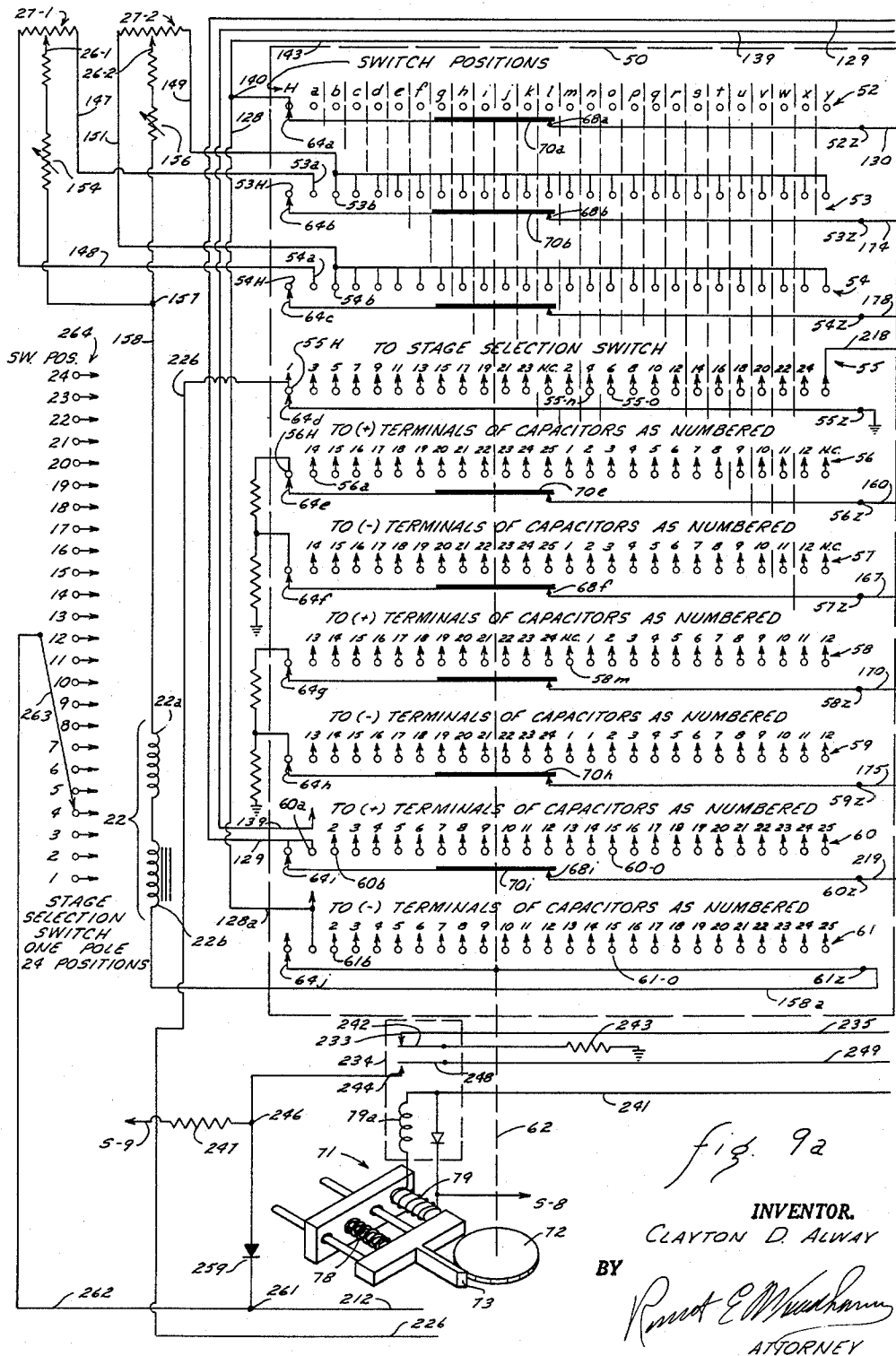
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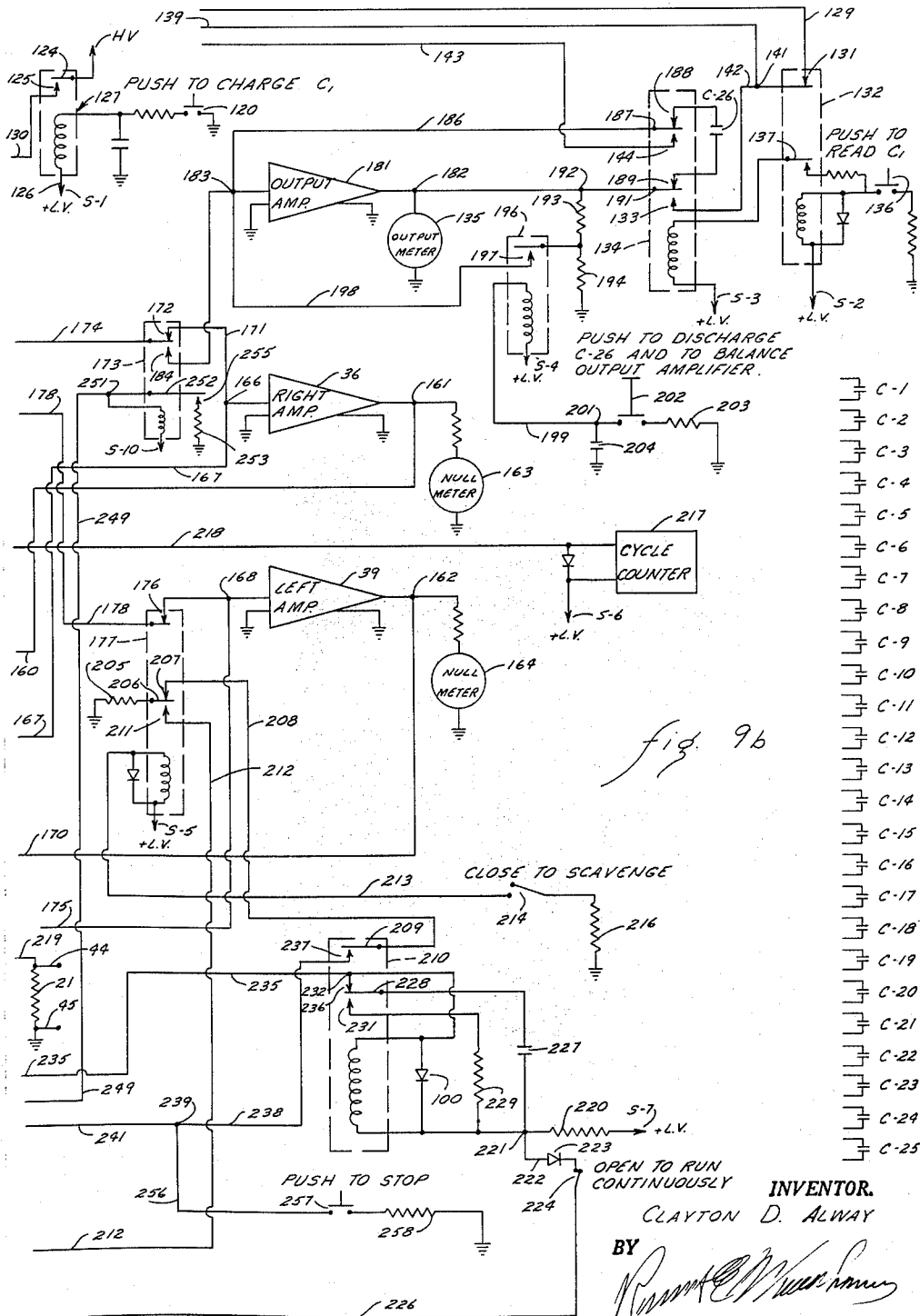
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5 Sheets-Sheet 5



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2,958,466

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21 Claims. (Cl. 235—184)

This invention relates to a computer and, more particularly, it relates to a computer adapted to indicate the results obtainable by operation of a multi-stage, liquid-liquid extraction process or of a fractional distillation column under a predetermined set of conditions by simulating electrically the operation of such a column.

It has long been understood that a variety of controllable results can be obtained by properly selecting the conditions under which a multi-stage, liquid-liquid extraction process or a fractional distillation column is to operate. The mathematical techniques by which the results obtainable for a given set of operating conditions may be manually determined are well understood and are not particularly difficult to carry out, but where a large number of possible operating conditions exist, it can be extremely tedious and time-consuming work to determine by manual methods the particular set of operating conditions capable of giving optimum results in a given situation.

The feed introduced into a liquid-liquid extraction process or a fractional distillation column is normally a mixture of two or more components and the purpose of the extraction operation is to separate one or more of said components from the remainder. Referring particularly to the liquid-liquid extraction process, the mixture may be intimately mixed or contacted with a liquid comprising two immiscible solvents, one of which will retain a larger proportion of the component which it is desired to separate, and the other of which will retain a larger proportion of the remainder of the mixture. After the mixing or contacting is effected, in at least some instances by shaking the mixture in the liquid body, the solvents are then separated, each solvent containing a known proportion of the component of the mixture. This process may then be repeated as many times as desired for carrying the extraction to whatever limits may be feasible.

Assuming the solubility of the desired component of the feed in the selected liquid solvents to be precisely known, as it usually is, the details of a given extraction operation can be readily predicted by following known techniques through simple multiplication procedures, which can be carried out rapidly as by a slide rule or other digital calculator, and within an accuracy which is normally commercially acceptable. However, even where a slide rule or a mechanical calculator is used to carry out the multiplying steps of the calculation, the number of such calculations is often so great that the manual procedure is relatively slow and an extremely large number of hours can be expended by highly paid personnel for the purpose of determining, for example, which group of many possible extracting solvents and/or the proportions thereof, can be most effectively and economically used for separating a desired substance from a given mixture including such substance.

Thus, it is desirable to provide a computer which will be capable of rapidly providing accurate data corresponding to that which is produced, in much slower fashion, by manual calculations of skilled personnel.

2

In the usual type of analog computer, all of the elements and operations of the actual system are represented simultaneously by computer components and operations. Where such a computer must be capable of simulating a multi-stage, multi-cycle, liquid-liquid extraction or fractional distillation operation, the cost and bulk of the computing components necessary to represent all of the elements and operations of the actual system simultaneously is prohibitive.

In the usual type of digital computer, the problem to be solved is resolved into a sequence of single operations in which information is automatically stored, called up and computed for intermediate and final results as desired. Conventional digital computers having sufficient storage and programming capacity for solving a problem, as discussed above, involving multi-stages and multi-cycles are also bulky and expensive.

In devising a computer suitable for solving such a problem and having a minimum number of components, it has been found desirable to use techniques similar to those used in both analog and digital computers and so combining such techniques that a satisfactory apparatus is produced at minimum cost. In particular, the analog computer technique of utilizing separate components corresponding to the elements (or stages) of the physical system may be combined with the digital computer technique of utilizing a sequence of single operations (or cycles) of the physical system. In this manner a minimum of components may be repetitively utilized to simulate the actual operation system, even though such operation may involve many stages and cycles.

In devising a particular device incorporating the principles broadly stated above, one major problem was to provide a circuit in which the division of an electrical charge could be caused to simulate quantitatively the separation of the desired components in the kind of mixture mentioned above, e.g. in a conventional fractional distillation column. This presented the further problem, among others, of storing a given and measurable electrical charge in a suitable storage device, and then transferring said charge through controllable divider means so that the entirety of the charge was divided in a predetermined manner and was received for further storage in other storage devices.

Accordingly, a principal object of the invention has been to provide a computer capable of simulating an action wherein an original quantity is divided, selected fractions thereof recombined and selected portions of the recombined fractions divided into further selected fractions, and a determination made of the ratio between the original quantity and a selected one of such further selected fractions.

A further object of the invention has been to provide a computer capable of simulating the action of a liquid-liquid extraction or fractional distillation operation, e.g., by a multi-stage fractionating column.

A further object of the invention is to provide a computer, as aforesaid, capable of predicting the operation of a fractionating column under a wide variety of pre-selected operating conditions.

A further object of the invention is to provide a computer, as aforesaid, whose parameters can be readily adjusted to accommodate a wide variety of desired programming.

A further object of the invention is to provide a computer, as aforesaid, in which a determinable value of a selected electrical characteristic can be identified in a first device, can then be divided into predeterminable portions, and substantially the entirety of such portions subsequently transferred to other selected identifying devices.

A further object of the invention is to provide a computer, as aforesaid, in which a determinable quantity of

electrical charge can be stored in a first storage device, can then be divided into predeterminable portions, and substantially the entirety of such portions subsequently transferred to other selected storage devices.

A further object of the invention is to provide a computer, as aforesaid, in which the arrangement of such storage devices and means for transferring selected values of electrical charge from one storage device to another can be made readily capable of simulating quantitatively the action of a multi-stage fractional distillation column, i.e., a series of fractionating operations.

A further object of the invention is to provide a computer, as aforesaid, in which relatively few storage devices and charge transferring means will be required.

A further object of the invention is to provide a computer, as aforesaid, in which only a few storage devices and charge transferring means will be needed, but in which there is available appropriate switching means by which said devices may be utilized successively and in such selectable combinations that the operation of the machine will simulate a large number of fractionating operations.

A further object of the invention is to provide a computer, as aforesaid, which will be of sufficiently simple construction as to be relatively inexpensive to manufacture and convenient to maintain in accurate and effective operating condition.

A further object of the invention is to provide a computer, as aforesaid, which will be capable of easy and accurate operation by anyone having sufficient technical ability to carry out the manual computations above described.

Other objects and purposes of the invention will be apparent to persons acquainted with apparatus of this general type upon reading the following disclosure and inspecting the accompanying drawings.

In the drawings:

Figure 1 is a schematic flow diagram for a four stage, three cycle counter-current multi-stage extraction operation which may be computed manually or by the computer of the present invention.

Figure 2 shows diagrammatically the transfer of the selected electrical characteristic, as a charge on a capacitance, between the several identifying devices, the showing being in a manner corresponding to the illustration of the flow diagram shown in Figure 1 but indicating more possible stages of operation.

Figure 3 is a diagrammatic illustration of a circuit by which an electrical charge is conveyed from one storage device into other storage devices.

Figure 4 is a graph illustrating the time-current relationships of the discharge current in the circuit of Figure 3.

Figure 5 is a graph, similar to Figure 4, of the time-current relationships in a modified circuit.

Figure 6 is a fragmentary, partially schematic, top view of a desirable switching mechanism.

Figure 7 is a fragmentary view of the switching mechanism of Figure 6 as appearing when viewed from line VII—VII of Figure 6.

Figure 8 is a somewhat schematic oblique view of a part of the switching mechanism of Figure 6.

Figure 9a is a wiring diagram of a portion of the computer circuit selected to illustrate the invention and embodying the basic circuit shown in Figure 3.

Figure 9b shows the remainder of the selected computer circuit, the connections appearing along the right-hand margin of Figure 9a again appearing along the left-hand margin of Figure 9b.

Figure 10 is a diagrammatic illustration of an alternate basic circuit.

IN GENERAL

In general, the invention consists of apparatus involving a plurality of electrical components by which an initial value of a selected measurable electrical character-

istic can be isolated by a first identifying device, then divided and conducted as divided into other identifying devices, then redivided and reconducted into still further identifying devices, in such a manner that the value of the selected characteristic ultimately appearing at a final measuring device will bear a ratio to said initial value which will have a known relationship with the ratio borne to the quantity of the original mixture by the quantity of material separated from said original mixture by a fractional distillation or extraction operation operating under predetermined conditions. Thus, by this apparatus in which the parameters can be adjusted to correspond with the operating conditions of the fractionating column being investigated, it is possible to determine, within a very short period of time, the results which can be obtained from a column operating under a given condition, and the calculations repeated for enough different possible operating conditions of said column to determine the optimum operating conditions thereof. In this manner, the optimum operating conditions of the column can be determined in a matter of a few minutes, whereas manual calculation using the same information would require many days or weeks to determine optimum operating conditions.

In accomplishing this, it has been discovered that an electrical charge, as distinguished from voltage, current, or energy value, provides an electrical characteristic which is effective and convenient for the purposes above defined and much of the present invention including the following described circuitry is based thereon. However, the broader aspects of the invention are not so limited and could be practiced with other characteristics, such as voltage.

Thus, in the present illustrative embodiment of the broad concept, specific electrical circuitry has been provided by which substantially the entirety of the initial value of an electric charge can be transferred from an initial storage device to one or more further storage devices. This has been accomplished by utilizing a high gain D.C. amplifier around each of the storage devices to which charge is being transferred which functions so that the residual amount of charge remaining in the initial storage device is sufficiently small as to be negligible. The problem has been further handled by providing a switching device capable of connecting and reconnecting the same storage devices in successive patterns so that said devices are used to represent a large number of different positions in a given extraction sequence. This has the twin advantages of (1) reducing the size and complexity and therefore the cost of the calculator, and (2) of picking up and returning into the analogy of the extraction operation the above mentioned residual increments of charge and thereby still further reducing the error which otherwise would accumulate in a given calculating operation.

In this manner, the apparatus is capable of rapidly performing many hundreds of thousands of mathematical computations analogous to the computations that would be involved in determining optimum operating conditions for a liquid-liquid extraction or fractional distillation process and to provide the desired information with a sufficiently high degree of accuracy, namely, wherein the error is of the order of under 5%, that it is within a commercially acceptable range.

DETAILED DESCRIPTION

In proceeding with the detailed description of the apparatus selected to illustrate the present invention, certain numerical values will be utilized in connection with different portions of the apparatus constituting the embodiment here chosen for illustrative purposes. It should be thoroughly understood, however, that except as expressly indicated otherwise, the values mentioned are for illustrative purposes only and are not limiting.

Similarly, reference will frequently be made to "upper

5

and lower contacts," and "armature positions," of the several relays referred to in the description. This again is for convenience in description and has no limiting significance with respect to the actual position of such relays in a given operative embodiment. Reference will also be made frequently hereinafter to the "transferring" of a charge from a first capacitor to a second capacitor. This language will be understood to mean merely the charging of such second capacitor to a value determined by the value of a previous charge in the first capacitor, the first capacitor discharging simultaneously with the charging of the second capacitor. The term "transferring" as so used will neither include nor preclude the thought that any of the current flowing out of the first capacitor actually or necessarily flows into the second capacitor. It will indicate merely the procedure stated above and nothing more.

In carrying out this description, reference will be made first to the type of procedure involving computations which the present apparatus is adapted to perform; next, attention will be directed toward certain novel components of the apparatus, both electrical and mechanical; and lastly the entire apparatus utilizing these components will be described and the operation thereof pointed out.

Turning first to the general type of extraction procedure and the computations therefor, which the present computer is adapted to perform, attention is first directed to the schematic flow diagram of Figure 1.

The feed F and the solvent S are fed to a container 1 (the first extraction stage of the first cycle), mixed therein, and then separated to provide the raffinate R_{1-1} and the extract E_{1-1} , said extract containing a portion of the component which it is desired to recover. The extract E_{1-1} is fed to a further container 3 for the second extraction stage of the first cycle and separated into raffinate R_{2-1} and extract E_{2-1} , the extract E_{2-1} containing a quantity of the desired component in more purified form. The raffinate R_{1-1} which had been stored in container 2 is then mixed with raffinate R_{2-1} in container 7 to extract more of the desired component from raffinate R_{1-1} . This is the first stage of the second cycle. The mixture is then separated into raffinate R_{1-2} and extract E_{1-2} . Similarly in the second stage of the second cycle, the extract E_{1-2} of the first stage of the second cycle is mixed with the raffinate R_{2-2} of the third stage of the second cycle and separated into extract E_{2-2} and raffinate R_{2-2} . Each extract for each advancing stage of each cycle contains the desired component in progressively more purified form and certain of the extracts, such as E_{4-2} and E_{4-3} , may be sufficiently pure that they can be removed from the extraction process. Thus, it will be seen that each stage of each cycle of the extraction process involves a combination of two quantities and subsequent division thereof in fixed proportions which are then fed to subsequent stages and cycles. The relative proportion of the weight of the desired component in the extract and raffinate of any given stage of any cycle can be determined by known chemical computations. This relative proportion may be the same for each of the stages or it may be different depending on process variables.

Referring now to one specific example wherein a mass containing 100 units by weight of the desired component A was deposited in a container together with two solvents which were mixed and heated to evolve vapors. The container is the first stage of the process. The solvents were such that 91.7% of the weight of A supplied to the container remained therein while 8.3% of the weight of A was carried in the vapors evolved from the container. These vapors were fed to a fractional distillation column having a series of vertically spaced trays which constitute the remaining stages of the process. The operation of the column was such that the vapors evolved (the extract) from each stage included 64.5% by weight of the weight of the desired component supplied thereto while the remainder (35.5%) of the weight of the desired component remained in the raffinate. As illustrated in Fig-

6

ure 1, the extract from the fourth stage contained the desired component in sufficiently pure form that it could be withdrawn from the apparatus. While the weight ratio of the desired component in the extract and raffinate is one value in the first stage and is a second value for the remaining stages it is apparent that such ratio could be the same for each stage or different for each stage if desired. Sample calculations showing the amounts of the desired component in the respective extracts and raffinates are indicated in Figure 1.

While Figure 1 indicates in solid lines a supply of feed F containing the desired component only to the first stage, it will be apparent other feeds F could be supplied to other stages of the process if desired and this is indicated in Figure 1 by broken lines.

In the present invention an analogy to the above described physical operation is provided by supplying an electrical charge in a known quantity to an electrical storage device C-1 (Figure 2) corresponding to the container 1 mentioned above and this charge is then divided and conducted in its entirety, or substantially so, into further storage devices C-13 and C-14 corresponding to containers 2 and 3. The values of electrical charge in storage devices C-13 and C-14 corresponding to containers 2 and 3 are then further divided and/or recombined to correspond to the physical process performed in containers 7 and 8, thereby completing the first cycle of the computing operation.

However, in the analog process the same capacitor C-1 is used to correspond to container 7 as was used to correspond to container 1. Likewise, in the next cycle the same capacitor C-2 is used to correspond to container 8 as used in the first cycle to correspond to container 4. Thus, by reconnecting and re-using the same capacitors, any residual value of electrical charge remaining in each of said capacitors, after they are supposedly discharged, will be reintroduced into the system and such residue will not constitute a constantly accumulating error in the computer. In this manner, the invention not only secures an economy of equipment but also provides a high degree of accuracy.

The charge transferring circuit

As above indicated, one of the critical points of the present invention is the circuit making possible the transfer of the electrical charge from one storage device to another storage device and effecting thereby the transfer of substantially all of the charge out of said one storage device.

Referring to Figure 3, there is shown a resistance 21 connected at one end to ground and at its other end to one side of a variable inductance 22. The other side of said inductance 22 is connected to one side of a supply capacitor 23 whose other side is connected to the slider of the variable resistance 24. The other terminal of said resistance 24 is connected to the slider 26 of a variable resistance, or divider, 27. The respective ends of the resistance element of said divider 27 are connected through switches 28 and 29 to junction points 31 and 32 of the integrators 33 and 34.

The integrator 33 includes a D.C. amplifier 36 of any conventional kind connected between the junction point 31 and an output terminal 37. A receiving capacitor 38 is connected between the junction point 31 and the output terminal 37 and is arranged around said D.C. amplifier 36. A terminal 42 connects the integrator 33 to ground. Integrator 34 is constructed similarly to the integrator 33, utilizing D.C. amplifier 39 and a receiving capacitor 40, and an output terminal 41. A terminal 43 connects integrator 34 to ground. The output of integrator 33 is read as a potential across the terminals 37 and 42, and the output of integrator 34 is read as a potential across the terminals 41 and 43. Both of said D.C. amplifiers have a very high gain between their input and their output terminals, such as a gain of 1 to 10,000. A suitable D.C. amplifier for this purpose is illustrated at

page 225 in Korn & Korn "Electronic Analog Computers" (McGraw Hill Book Company, Inc., New York, N.Y., second edition, 1956).

Where it is desired to use an oscilloscope, it is conveniently connected by conductors 44 and 45 across the resistance 21.

Operation of the charge transferring circuit

The operation of the above described charge transferring circuit will be readily understood. With the supply capacitor 23 charged to isolate a quantity of electric charge, the capacitors 38 and 40 being intended to collectively receive said charge, it will be recognized that if the D.C. amplifiers were not present in the circuit the charge from the capacitor 23 would enter the capacitors 38 and 40 until the entire system would reach a point of equilibrium with one-third of the charge remaining in the supply capacitor, assuming all three capacitors to be each of the same capacity. However, since the D.C. amplifiers are placed in parallel with each of the receiving capacitors 38 and 40 with the input terminals of the amplifiers connected respectively to the junction points 31 and 32, the ratio of the potential with respect to ground of junction point 31 and output terminal 37 will equal the gain ratio of amplifier 36 and similarly with junction point 32, output terminal 41 and amplifier 39. The potential between junction point 31 and output terminal 37 will be proportional to the charge on capacitor 38 and the potential between junction point 32 and output terminal 41 will be proportional to the charge on capacitor 40. Thus, the voltage at said junction points 31 and 32 is held at a very low level. This will discharge capacitor 23 to a correspondingly low level and conduct the energy previously contained therein in substantially its entirety to the receiving capacitors 38 and 40. Said energy is divided between said receiving capacitors in a ratio determined by the position of the slider 26 on the divider 27.

The function of the inductance 22 is to slow the initial discharge current flowing from the supply capacitor 23 and to increase the final discharge current and thereby give the discharge current a pattern as appearing in Figure 4. The circuit including resistance 21, inductance 22, capacitor 23, resistance 24 and resistance 27 is adjusted by adjustment of inductance 22 and resistance 24 to comprise a critically damped circuit. The characteristics of such a circuit are treated in Henney "Radio Engineers Handbook" 3rd ed. pages 127, 128. By having the discharge current low at the beginning of a discharge operation, any possible error due to lack of synchronism in the closing of the switches 28 and 29 is minimized. Further, the critically damped circuit will quickly bring the discharge current back to zero and will effect a substantially complete discharge of the capacitor. If said inductance is omitted the pattern of the discharge current of the capacitor 23 will be as appears in Figure 5. Under these circumstances if the switches 28 and 29 fail to close exactly at the same time, the point at which one is closed and the other is open will occur when the current is at a maximum and hence the error resulting from lack of synchronism will be much greater. Since it is normally impossible, or at least extremely difficult, to close two switches at exactly the same moment, it will be appreciated that the use of the inductance 22 will greatly add to the accuracy of the apparatus. Likewise, if the critically damped circuit were not utilized, the capacitor 23 would require a longer time to discharge and would probably retain an undesirably large charge.

Switching apparatus

Since much of the present invention lies in the mechanism by which the several capacitors are connected to each other and to the other components of the charge transferring circuits, it is now believed advantageous to direct attention to the mechanics of one satisfactory switching mechanism effective for this purpose. It will be

understood that this particular switching mechanism is illustrative only and is by no means the only switching mechanism which can be used for this purpose. However, this particular switching mechanism has been used effectively in a satisfactory working embodiment of this apparatus and is accordingly utilized herein for illustrative purposes. It will be understood that no novelty is claimed for the switching mechanism, as such, but only for the circuitry of which the switch is a part. One satisfactory switch for this purpose is made by G. P. Clare & Co., Chicago, Illinois, under the name of Ten Level Spring-Driven Stepping Switch, type 26.

Referring to Figures 6, 7 and 8, for convenience the switch mechanism 50 will be assumed to be in a position such that the axis of its shaft 62 is in a vertical position. Thus, reference made to horizontal rows and to vertical rows of the several switch terminals will be understood to mean rows which are transverse to, and parallel with, the axis of shaft 62, respectively. However, this reference is only for convenience in description and in no sense will be taken as limiting the position in which said switch mechanism 50 may be positioned for operation.

The switching mechanism 50 comprises a frame structure 51 of generally hemicylindrical shape, having a rotatable shaft 62 suitably mounted on the axis of said frame and arranged for rotation therewith.

The hemicylindrical frame 51 is provided with a plurality of terminals arranged in horizontally and vertically aligned rows circumferentially around the periphery thereof. The horizontally arranged rows are indicated by reference numerals 52 to 61 (Figure 8). The vertically arranged rows are indicated by the reference characters H and "a" to "z" inclusive (Figure 6), it being understood that each vertical row includes one terminal in each of the horizontal rows which is vertically aligned with corresponding terminal in the adjacent horizontal row. Vertical row H is adjacent vertical row "a." The terminals 52H to 61H and terminals 52a to 52y through 61a to 61y, inclusive, constitute selectable terminals extending inwardly of the frame 51 for contact with, and selection by, the hereinafter mentioned movable contact members. The terminals 52z to 61z inclusive constitute fixed terminals which are in constant contact with said movable contact members as hereinafter described in more detail.

Movable contact members 64a to 64j are mounted on, and for rotation with, the shaft 62, each of said movable contact members being comprised of oppositely extending arms 67 and 69. Each of said arms is comprised of pairs of prongs as illustrated at 67a and 67b (Figure 7). Said pairs of arms are arranged for contacting the inward ends of each of the selectable terminals at the opposite sides thereof. Each contact member is adapted successively to engage all of the terminals in one of the horizontal rows 52 to 61.

The fixed terminals 52z to 61z, inclusive, extend inwardly to points adjacent the shaft 62, and have oppositely flared inward ends 68 (Figure 7), which contact the slip ring 70 on each of the movable contact members 64 for effecting electrical contact therewith. Thus, each of the fixed terminals 52z to 61z, inclusive, is in constant electrical connection with one of the movable members 64a to 64j, respectively.

Mechanism 71 is provided for effecting stepwise rotation of said shaft 62 and the movable contact members carried thereby. Suitable means for this purpose include a ratchet 72, fixed on shaft 62 for rotation therewith. A pawl 73 is adapted to operatively engage and move the ratchet 72 in step-by-step fashion. The pawl 73 is supported by rods 74 and 76 on a base 77 which is fixed with respect to the frame of the apparatus. A spring 78 constantly urges said pawl toward said ratchet and an electromagnetic device 79, when energized, draws said pawl away from said ratchet. Thus, energization of said electromagnetic device 79 has the result of cocking said pawl and deenergization thereof permits the spring 78 to urge

the pawl against the ratchet and effect rotation of shaft 62 and of the movable contact members 64 thereon a distance sufficient to move them from their position of contact with one vertical row of selectable terminals to the next adjacent vertical row of selectable terminals. Suitable detent means, not shown, are provided to stop movement of the shaft 62 at the proper location. The use of oppositely extending arms 67 and 69 on each of the movable contacts 64 permits the use of a hemicylindrical arrangement of contacts as a matter of convenience, yet permits the shaft 62 to operate through 360° of rotation for successive operations.

Construction of entire apparatus

With the several novel components of the apparatus described, it is now appropriate to direct attention to the overall organization of the apparatus and to the circuitry used therein. Accordingly, attention is directed to Figures 9a and 9b, showing diagrammatically the electrical portion of the apparatus including the switch mechanism 50 above described in detail. The mechanism here shown includes a schematic indication of the shaft 62 driven step wise by the driving mechanism 71. The fixed terminals 52z to 61z are indicated at the right-hand portion of the broken line enclosure designating the switching structure 50, and the horizontal rows of contact points indicate the several levels 52 to 61 of selectable terminals shown in more detail and described above. The several movable contact members 64a to 64j by which the fixed terminals in the respective horizontal rows 52 to 61 are selectively connectable to the selectable terminals in the respective horizontal rows. The lines connecting said arrows to the indication of the shaft 62 schematically indicate the mechanical structure by which said shaft moves said contacts 64a to 64j from one contact to another.

As will be discussed in greater detail hereinbelow, only contact 52H of row 52 is utilized in the disclosed embodiment and it functions to initially charge the capacitor G-1 as elsewhere herein described fully. The contacts of rows 53 and 54 are connectable to the dividers 27-1 and 27-2 whereby the divided charge therefrom may be supplied to the right and left amplifiers and to the capacitors connected thereto. The contacts of row 55 are connectable to the terminals, as numbered, of the output stage selection switch 264. The contacts of rows 56 and 57 are connectable to the positive and negative terminals of the capacitors, as numbered, and are adapted to connect such capacitors as receiving capacitors for the integrator 33 including right amplifier 36. The contacts of rows 58 and 59 are connected to the positive and negative terminals, respectively, of the capacitors, as numbered, and are adapted to connect such capacitors as the receiving capacitors for the integrator 34 including the left amplifier 39. The contacts of rows 60 and 61 are connected to the positive and negative terminals, respectively, of the capacitors, as numbered, and are adapted to conduct the charge thereon to the dividers 27-1 and 27-2.

A suitable source of low voltage, as 30 volts, D.C. potential is supplied to points of sources S-1 to S-10 inclusive in the circuit through any suitable means.

Now turning to the particular circuitry utilized in the present embodiment, source S-1 (Figure 9b) is connected to an input wire 126 which is connected through the winding of a relay 127 and thence through a starting switch 120 to ground. A high voltage, as 100 volts, D.C. source H.V. is connected to the armature 124, thence through the contact 125 of the relay 127 and through conductor 130 to the fixed terminal 52z of the row or switch level 52. In the drawing, it is indicated that the negative terminal of said source is connected to the fixed terminal 52z. This is strictly a matter of choice and will depend primarily upon whether the meters used to measure the energy present at any given time in the energy storage devices respond to positive potential or to negative potential, and which one is uti-

lized in any given case is a matter of convenience only. The selectable terminal 52H of said switch level 52 is connected, to a junction point 140, thence by conductors 128 and 128a to the negative side of the first capacitor C-1 for charging same. The positive side of said capacitor C-1 is connected by the conductor 139 to the point 141, thence through the contact 131 of the relay 132 and through conductor 129 to selectable terminal 60a, thence by movable contact member 64i to fixed terminal 60z and thence to ground. An initial reading switch 136 connects the winding of the relay 132 from a low voltage D.C. source S-2 to ground, in order that the closing of said switch will energize said relay. Energizing of said relay will close the armature 137 of the relay 132 and thereby connect the low voltage source S-3 through the switch 136 to ground, thereby energizing the winding of the relay 134 for effecting contact of its lower armature against the contact 133. When this happens the connection at contact 131 is broken and the positive side of capacitor C-1 is connected from point 141 through contact 133 to the output meter 135 and thence to ground. The selectable terminal 52H is also connected to a junction point 140 and thence by the conductor 143 to the contact 144 of the relay 134. The operation of the mechanism immediately above described will be described in more detail hereinafter, but briefly for the purpose of the present description, its purpose is to effect the initial charging of the capacitor C-1 and to measure on the output meter 135 the value of such charge.

The current dividers by which the charge in C-1 is divided as it is conducted to other capacitors appear at 27-1 and 27-2. These dividers correspond to the divider 27 above described in connection with Figure 3, but inasmuch as in the specific embodiment here chosen for illustrative purposes there are two such dividers utilized, they will, when referred to individually, be referred to as 27-1 and 27-2 but collectively they will be designated as dividers 27. Two such dividers are shown in the present embodiment inasmuch as two ratios of division of the material A being separated by the fractionating operation are normally sufficient for most uses and conform to the generalized showing of the physical operation appearing in Figure 1. Where only a single extracting solvent, and therefore only one ratio of division, is utilized, only one of the two dividers 27-1 and 27-2 will be used. Where more than two such divisions are to be used, the circuitry of the computer will be modified accordingly, but the manner of said modification will be apparent from the description given following.

The first divider 27-1 has one end of its resistance element connected by a conductor 147 to the selectable terminal 53a in the row of switch level 53. The other end of said resistance is connected by conductor 148 to the selectable terminal 54a in the row or switch level 54. One end of the resistance associated with the divider 27-2 is connected by conductor 149 to the selectable terminal 53b and all of the subsequent selectable terminals 53c through 53y. The other end of the resistance of divider 27-2 is connected by a conductor 151 to the selectable terminal 54b and to all of the remaining selectable terminals 54c through 54y of the row or switch level 54. The sliders 26-1 and 26-2, corresponding to slider 26 in Figure 3, of the dividers 27-1 and 27-2, respectively, are connected through variable balancing or adjusting resistances 154 and 156, respectively, to a junction point 157 and thence by a conductor 158 through inductance 22 to the fixed terminal 61z of the row of switch level 61.

Preferably, said inductance 22 comprises a pair of inductances 22a and 22b in series with each other, one being of relatively high inductance, such as 200 henrys, and one of relatively small inductance such as 30 microhenrys, for the purpose, as is conventional, of insuring

the presence of an inductance in the system through a wide range of frequencies.

The D.C. amplifiers 36 and 39 referred to in connection with Figure 3 appear in Figure 9b and are marked as right amplifier and left amplifier to indicate their relationship with the rightwardly and leftwardly diverging lines in Figures 1 and 2 for convenient reference and explanation of the operation as appearing hereinafter. The output ends of said amplifiers 36 and 39 are connected to the junction points 161 and 162, respectively, thence through null meters 163 and 164, respectively, to ground. Said null meters are utilized solely for the purpose of initial balancing and adjusting of the apparatus.

The input side of the right amplifier 36 is connected through a junction point 166 and thence through the conductor 167 to the fixed terminal 57z of the row or switch level 57. The input of the left amplifier 39 is connected to a junction point 168 and thence through a conductor 175 to the fixed terminal 59z of the row or switch level 59. The junction point 166 is also connected by a conductor 171 through the contact 172 of the relay 173 to the conductor 174 and thence to the fixed terminal 53z of the row or switch level 53. The junction point 168 is also connected through the contact 176 of the relay 177 to the conductor 178 and thence to the fixed terminal 54z of the row or switch level 54.

An output amplifier 181 is provided having its output connected to a junction point 182 and thence to the output meter 135. The input side of said output amplifier 181 is connected to a junction point 183, thence to a second contact 184 of the relay 173 and when the armature of said relay 173 is in the position opposite to the position shown in the drawing, said contact 184 is connected through the conductor 174 to the fixed terminal 53z. The junction point 183 is also connected by the conductor 186 to the armature 187 of the relay 134.

The output capacitor C-26 is connected at one of its ends to the contact 188 of relay 134 and at the other of its ends to the contact 189 of said relay. The second armature 191 of the relay 134 is connected through a junction point 192 to the junction point 182.

The junction point 192 is connected through a voltage divider comprising a pair of resistances 193 and 194 to ground. A point intermediate said resistances is connected to the armature of a relay 196 and the contact 197 of said relay is connected through a conductor 198 to the junction point 183. The winding of said relay 196 is connected at one of its ends to the low voltage D.C. source S-4 and is connected at the other of its ends by the conductor 199 to a junction point 201. Said junction point 201 is connected through a manually operable switch 202 through a resistance 203 to ground and is also connected to a capacitor 204 and thence to ground. Thus, closing of the switch 202 will connect the source S-4 through the winding of the relay 196 to ground and thereby energize said relay. When closed the switch 202 will permit capacitor C-26 to discharge as discussed in greater detail hereinbelow.

The relay 177 adjacent the left amplifier 39 has a second, or lower, armature 206 which is connected through a resistance 205 to ground. The contact 207 associated with said second armature 206 is connected to conductor 208 and thence to a first armature 209 of a relay 210. The other contact 211 associated with the second armature 206 is connected to a conductor 212 whose purpose will appear in more detail following.

The winding of the relay 177 is connected at one of its ends to a low voltage D.C. source S-5 and at the other of its ends through the conductor 213 to a normally opened scavenger switch 214 and thence through a low resistance 216 to ground. Thus, closing of the normally opened scavenger switch 214 will connect the source S-5 through the winding of the relay 177 to ground and thereby energize said winding for actuating of the relay.

A cycle counter 217 is preferably also provided and is connected at one of its sides to the low voltage source S-6 and at its other side through a conductor 218 to the last selectable terminal in an appropriate one of the rows or switch levels, here the row or switch level 55.

The circuitry appearing in the lower part of Figure 9b is primarily for the purpose of actuating the electromagnetic device 79 by which the shaft 62 is rotated in a step-wise manner.

Commencing with the low voltage source S-7, there is provided a connection through relatively low resistance 220, as 600 ohms, to a junction point 221. Said junction point is connected by a conductor 222 through a rectifier 223, thence through a normally closed switch 224 to a conductor 226 to the "home" position 55-H of the row or switch level 55.

Said junction point 221 is connected through a capacitor 227 to the lower armature 228 of the relay 210 and is also connected through a resistance 229 to the lower contact 231 of the relay 210. Said junction point is still further connected through the winding of the relay 210 to the junction point 232 and thence through conductor 235 to a contact 233 of a relay 234. The junction point 232 is also connected to the upper contact 236 of the relay 210. The contact 237 of said relay 210 is connected by a conductor 238 to a junction point 239 and thence by a conductor 241 to and through the winding 79a of the relay 234 and thence to the low voltage D.C. source S-8. The winding 79a is preferably the same winding as that which energizes the electromagnetic device 79 described above, but for the purpose here of convenience in illustration, the winding for the electromagnetic device 79 and the winding 79a for the relay 234 are shown as separate windings which are serially connected.

The first armature 242 of the relay 234 is connected through a resistance 243 to ground. The lower contact 244 of the relay 234 is connected through a junction point 246 to and through a relatively low resistance 247, such as 500 ohms, to the low voltage D.C. source S-9. The armature 248 of the relay 234 is connected by a conductor 249 to a junction point 251 adjacent the relay 173 and thence through the winding of said relay to the low voltage source S-10. The junction point 251 is also connected to the armature 252 of the relay 173. The contact 255 of the relay is connected through a relatively high resistance 253, such as 6.8K. ohms, to ground.

The junction point 239 is also connected to a conductor 256, thence through a normally open switch 257 to and through a low value resistance 258 to ground.

The junction point 246 (Figure 9a) is connected through a rectifier 259 to a junction point 261, said rectifier being poled to oppose flow of current from junction point 261 to junction point 246. Junction point 261 is connected by conductor 262 to the armature 263 of an output stage selection switch 264. Said switch has one contact for each of the discharging operations after the first one appearing in Figure 2, here 24 such contacts, which contacts are numbered and are connected to the correspondingly numbered selectable terminals in row or switch level 55.

Returning to the junction point 261, it is connected by the conductor 212 to the contact 211 of the relay 177. Therefore, upon energization of said relay a connection from point 261 to ground is made through conductor 212 and armature 206.

The fixed terminal 60z is connected by conductor 219 through the resistance 21 (corresponding to the resistance 21 appearing in Figure 3) to ground. The oscilloscope connections 44 and 45 are also shown on either side of the resistance 21 in Figure 9b.

Suitable oscillation damping devices may, if desired, be applied in parallel with each of the several relay windings, such as the rectifier 100 shown connected in parallel with the winding of the relay 210.

13 OPERATION

Turning now to the operation of the apparatus, reference will be made first to the operation of certain subgroups of the apparatus, after which the operation of the entire device will be described.

Switching mechanism

First, with respect to the means by which the electromagnetic device 79 is energized and thereby the shaft 62 is rotated, attention is directed to the lower part of Figure 9b.

Manual operation of the apparatus is obtained by closing the switch 257. This effects a connection from the source S-8 through said switch to ground which energizes the winding 79a of the relay 234 which winding is in series with the winding of the electromagnetic device 79. Thus the device 79 is energized simultaneously with the energizing of the relay 234, and the pawl 73 is retracted away from the ratchet 72. If the switch 257 is now open, the electromagnetic device 79 is de-energized and the spring 78 impels the pawl 73 against the ratchet 72 to turn it through one step or rotation. Such step is sufficient to move the movable contact members from one vertical row of selectable switch terminals to the next vertical row of selectable switch terminals. Repeated closing of said normally opened switch 257 will similarly effect further counterclockwise (Figure 6) progression of the movable contact members 64 across successive vertical rows of such selectable switch terminals.

During this operation the switch 224 remains closed and thus the junction point 221 is connected through the conductor 226, the selectable terminal 55-H, the movable contact member 64d thence through the fixed terminal 55z to ground. In this way the junction point 221 is maintained at ground potential so that the apparatus associated with the capacitor 227 and the relay 210 is not actuated. However, when it is desired to cause the switch shaft 62 to operate automatically in a stepwise manner, the switch 224 will be opened. This breaks the ground connection for the junction point 221 and effects a charging of the capacitor 227, whose other side is connected to ground through the armature 228, the contact 236, the junction point 232, conductor 235, the contact 233 of the relay 234 and the armature 242 associated therewith. The junction point 221 is also connected through the winding of the relay 210 and thence to junction point 232, conductor 235, and to ground. Thus, as soon as said capacitor 227 is charged, the potential at the point 221 will rise and effect a flow of current through the winding of the relay 210, through the junction point 232 and the upper contacts of the relay 234 and thence to ground. This energizes the relay 210 and moves its armatures into their lower positions, thus, closing the armature 209 against the contact 237 and thereby connecting the source S-8 through the winding of the relay 234 to and through the lower contact 207 of the relay 177 and thence to ground. This energizes the electromagnetic device 79 and retracts the pawl 73. Simultaneously, the lower armature 228 of the relay 210 is moved against the contact 231 and this permits the capacitor 227 to discharge through the resistance 229. Such discharge is controlled in time by the relative value of the capacitor 227 and of the resistance 229 in known manner. Simultaneously with the energizing of the electromagnetic device 79, the relay 234 is energized, thus opening the upper contacts thereof and breaking the circuit at contact 233 by which the winding of the relay 210 is energized. This de-energizes the relay 210 and permits its armatures to return to the positions shown in Figure 9b, which breaks the connection at the upper of its contacts 237 through which the winding of the relay 234 is energized, thereby de-energizing the electromagnetic device 79 and permitting the spring 78 to impel the pawl 73 against the ratchet 72 and thus effecting a counterclockwise (Figure 6) actuation of the switch 50.

14

Thus, the flow of electrical current started through the electromagnetic device 79 and the winding 79a of the relay 234 with the closing of the relay 210, and the energizing of the relay 210 terminate immediately upon operation of the relay 234, with the result that the flow of current through the electromagnetic device 79 and the winding 79a is immediately terminated. In this manner, the current flowing through said electromagnetic device 79 and winding 79a is provided as only a brief pulse, and this is desirable in order to secure rapid and accurate operation of the apparatus.

In the meantime, with the relays both returned to the positions as shown in Figures 9a and 9b, the capacitor 227 again charges and the cycle is repeated. It continues to repeat so long as the switch 224 remains open.

Cycle counter

Referring to the cycle counter, once during each cycle of operation the movable contact member 64d will come into contact with the last selectable terminal 55y and effect a connection from the source S-6 adjacent to cycle counter 217 through switch 224 to ground. This will effect one actuation of the cycle counter and thereby, in operations involving multiple cycles, it will provide a readable record of the number of cycles through which the machine has been actuated.

Preparing computer for a computing operation

In preparing the device for a computing operation, a predetermined value of electrical charge is first applied to the capacitor C-1 to represent the amount of material A, above discussed, which is originally supplied to the container 1 in the physical operation being studied. To do this, the operator closes the starting switch 120 which effects a connection between the source S-1 and ground whereby to close the normally opened contact of the relay 127. This effects a connection between the source HV by which potential is supplied through the fixed terminal 52z to the movable contact member 64a, thence to the home terminal 52H to the junction point 140, thence by the conductor 128 and the conductor 128a to the conductor connected to the selectable terminal 61a and thence to the negative terminal of the capacitor C-1. The positive terminal of the capacitor C-1 is connected to conductor 139, which latter is for convenience shown at the leftward end of the row or switch level 60. The circuit then follows conductor 139 to the junction point 141, through the normally closed contact 131 and thence back on the conductor 129 to the selectable terminal 60-H. From said terminal the circuit is traced through the movable contact member 64i through the fixed terminal 60z and thence by the conductor 219 to ground. This effects the charging of the capacitor C-1. The capacitor C-1 is always charged to its full capacity inasmuch as the output values are all in terms of ratios which can be applied as required to whatever specific value of material "A" is utilized in a given process.

In order to check the value of charge applied to capacitor C-1, the normally opened starting switch 120 is permitted to open and normally open switch 136 is now closed. This energizes the relay 132, opening the connection at the contact 131 and closing the connection involving the armature 137. Said last named closing completes the circuit from S-3 for energizing the winding of the relay 134 and moves the armatures 187 and 191 both downwardly against their respective lower contacts. With the opening of the charging switch 120 and the resultant opening of relay 125, the connection from the junction point 141 to the source HV is now open and the charging of the capacitor C-1 is discontinued. Hence, the voltage applied to the conductors 128a and 128 from the capacitor C-1 follows the conductor 143 to the contact 144 in the relay 134, thence through the armature 187 and the conductor 186 to the junction point 183. The positive terminal of the

15

capacitor C-1 is connected through the conductor 139 to the junction point 141 and thence through the lower contacts 133 of the relay 134 to its armature 191 and thence to the junction point 182. The connection of the meter between the junction point 182 and ground will effect a measurement of the potential between the points 182 and 183 and hence said meter will indicate the total charge now appearing on capacitor C-1.

The switch 136 may now be released to effect the de-energizing of the relays 132 and 134 whereby their armatures are returned to the position shown in Figure 9b and after suitable setting of the other controls of the apparatus, the device is ready to commence a computing operation.

Assuming now that the apparatus is intended to compute the amount of output at a given condition where the divisions effected in the respective stages are as indicated in Figure 1, the slider 26-1 of the first divider 27-1 is set for dividing the charge on capacitor C-1 between the conductors 147 and 148 connected thereto in the proportion indicated in Figure 1 for the first stage, namely, in this example, 91.7 percent on the conductor 148 and 8.3 percent on the conductor 147. Similarly, the slider of the divider 27-2 is adjusted in this particular example so that the potential appearing on the conductors 149 and 151 will constitute 35.5 percent of the charge on capacitor C-1 on the conductor 151 and 64.5 percent of the charge on capacitor C-2 on the conductor 149.

Assuming further the given fractionating process to be investigated will have only four stages, corresponding to the four stage physical process indicated in Figure 1, and will therefore take output samples from capacitor C-15 as appearing in Figure 2, the output stage selector switch 264 will be set with the armature 263 of said switch in its position 4 so that it will be connected with movable contact member 64d by the selectable contact 55n for reasons appearing elsewhere below. There is nothing to set with respect to the number of cycles of operation inasmuch as the computer will merely continue to operate for as long as the operator wishes to run it and he can stop it manually when the output increments for each cycle are reduced to a sufficiently low value that further computing is unnecessary. In this way, for example, the operator can quickly obtain the output per cycle of a proposed extraction procedure, graph same if desired, and then determine the number of cycles through which it will be economically feasible to operate the physical unit.

Starting of computing procedure

With the initial charge in capacitor C-1 and the value of such charge checked by the meter 135 and preferably recorded, and with the dividers 27 and the output stage selector switch 264 properly adjusted, the machine is ready to commence a computing operation.

While the computing operation can be carried out by successive operations of the manual step switch 257, as above described, it is assumed that it would normally be carried out by opening the switch 224 and permitting the switch 50 to proceed automatically as above described. The computing operation is the same in each case and hence it will be necessary only to describe one manner of operation. Inasmuch as the automatic operation will not only be the preferred method of operation but since it includes all of the procedures which the manual actuation through the switch 257 would require, a description of the automatic operation will be sufficient to effect a full disclosure.

Therefore, referring to the automatic operation, the same is initiated by opening of the switch 224. This, in the manner above described, effects successive step wise movements of the movable contact members 64 from one vertical row of selectable contacts to the next vertical row of selectable contacts in the switch 50 as determined by

16

the time-constant factor of the capacitor 227 and resistance 229.

With the movable contact members 64 all in the home position, namely, in the "H" row of terminals nothing will happen at this point. The first movement of the shaft 62 will place the movable contact members 64 on the vertical row "a" of terminals and this will effect the following.

With the negative side of the capacitor C-1 now connected to the selectable terminal 61a, said capacitor will have a connection with the conductor 128a, but with the circuit broken at the relays 127 and 134 there will be no current travel in this direction. Accordingly, the discharge from the capacitor C-1 will pass from the selectable terminal 61a through the movable contact member 64j and through the fixed terminal 61z and hence by the conductor 158a through the inductance 22 to the junction point 157. Inasmuch as the circuit for the divider 27-2 is open at the selectable terminals 53b and 54b, the circuit will be complete only through the slider 26-1 and thence through both sides of the divider 27-1 to the selectable terminals 53a and 54a (corresponding to the connection from capacitor 23 in Figure 3 through the circuit divider 27 to the switches 28 and 29). With the movable contact members 64b and 64c now in contact with selectable terminals 53a and 54a, circuits are completed through the fixed terminals 53z and 54z, respectively, to the junction points 166 and 168, respectively, and thence into the leftward, or input, sides of the amplifiers 36 and 39. The output ends of said amplifiers are connected, respectively, through suitable null meters 163 and 164 to ground. The junction point 166 is at this time also connected through the conductor 167 to the fixed terminal 57z and thence through the movable contact member 64f to the negative terminal of the capacitor C-14, which capacitor corresponds to the capacitor 38 in Figure 3 and to the container 2 in Figure 1. The positive terminal of capacitor C-14 is then connected through the movable contact member 64e and the fixed terminal 56z to the junction point 161. Thus, the right amplifier 36 and the capacitor C-14 are connected in parallel with respect to each other between the junction points 166 and 161.

Simultaneously, the junction point 168 is connected by the conductor 175 through the fixed terminal 59z and the movable contact member 64h to the negative terminal of the capacitor C-13 and the positive terminal of said capacitor is connected through the movable contact member 64g through the fixed terminal 58z, conductor 170, and thence to the junction point 162. Thus, the capacitor C-13 becomes connected in parallel with the left amplifier 39 between the junction points 162 and 168, and corresponds to capacitor 40 in Figure 3. This effects a discharge of the capacitor C-1 into the capacitors C-13 and C-14 in ratios determined by the position of the slider 26-1 of the divider 27-1 in a manner following the description above given in respect to the unit circuit shown in Figure 3. Further, for reasons above set forth in connection with Figure 3, substantially all of the charge contained within the capacitor C-1 will be transferred to the capacitors C-13 and C-14.

The time constant system including the capacitor 227 and the resistance 229 is of such value that by the time the electromagnetic device 79 is actuated to move the movable contact members 64a to 64j, through the next step, a substantially complete transfer of charge from the capacitor C-1 to the capacitors C-13 and C-14 will have been effected. When such movement of the movable contact members takes place, and said members contact the "b" contacts of the several selectable terminals in the rows or switch levels 52 to 61, inclusive, a set of connections will effect a condition corresponding to the third stage, first cycle, connections shown in Figures 1 and 2.

Even though in this first cycle of operation there is

no charge on any of the capacitors C-2 to C-12, the connections thereto will proceed regularly as shaft 62 rotates and hence this point in the description will be taken as a convenient place to describe the connections brought about by further rotation of the shaft 62 with the understanding that such connections will effect transfer of electrical charges only in subsequent cycles of operation. Here, however, the second divider 27-2 is substituted for the first divider 27-1 in the circuit. Thus, the capacitor C-2 has its positive terminal connected through the selectable terminal 60b, the movable contact member 64i and the fixed terminal 60z, thence through the conductor 219 to ground. Said capacitor has its negative terminal connected through the selectable terminal 61b through the movable contact member 64j and the fixed terminal 61z, thence by the conductor 158a through the inductance 22 and the conductor 158 to the junction point 157. Now, however, the divider 27-1 is out of the circuit inasmuch as the movable contact members 64b and 64c are no longer in contact with the selectable terminals 53a and 54a. Instead said movable contact members are in contact with the selectable terminals 53b and 54b and accordingly the divider 27-2 is connected into the circuit. Thus, the connection continues from the junction point 157 through the divider 27-2 through the conductors 149 and 151 to the selectable terminals 53b and 54b, respectively, thence through the movable contact members 64b and 64c, respectively, to the conductors 174 and 178 and to the junction points 166 and 168. Said junction point 166 is also now connected through the conductor 167 and the movable contact member 64f to the terminal 57b thence to the negative side of capacitor C-15 and the positive side of said capacitor is connected by terminal 56b to the movable contact member 64e and the fixed terminal 56z to the junction point 161. Thus, the capacitor C-15 is connected in parallel with the right amplifier 36 between the junction points 166 and 161. Similarly the left amplifier 39 is connected through the conductor 175 to the terminal 59b thence to the negative side of capacitor C-14 and the positive side of said capacitor is connected through terminal 58b, through the movable contact member 64g to the junction point 162. Thus, the capacitor C-14 is now connected in parallel with the left amplifier 39 and between the junction points 168 and 162. This, as will be seen by reference to Figures 1 and 2, compares with the third stage of the first cycle of operation of the extraction process.

As the shaft 62 continues to advance step wise, the capacitors will be connected, disconnected and reconnected in a manner to follow the pattern shown in Figure 2.

As the movable contact members 64i and 64j reach position "m" the capacitor C-13, which was charged in the first stage above described corresponding to position "a," will now be connected for discharge. The positive terminal of capacitor C-13 is connected through the movable contact member 64i to ground and the negative terminal thereof is connected through the movable contact member 64j through the conductor 158a, inductance 22 and conductor 158 to the junction point 157. The divider 27-2 is still in the circuit and hence said circuit continues from the junction point 157 through the conductors 149 and 151, thence through the movable contact members 64b and 64c to the fixed terminals 53z and 54z. The circuit further continues in the manner previously described to the junction points 166 and 168, respectively. The junction point 168 is now connected through the fixed terminal 59z and the movable contact member 64h to the negative terminal of the capacitor C-1, but the movable contact member 64g has no connection since terminal 58m is open, hence the circuit is broken at this point. This latter corresponds to the

left branch from the first stage in the second half of the first cycle as shown in Figures 1 and 2.

The junction point 166 is, however, connected through the fixed terminal 57z to the negative side of the capacitor C-1 and the positive side of capacitor C-1 is connected to the fixed terminal 56z, thence to the junction point 161. Thus, capacitor C-1 is now connected as a receiving capacitor in parallel with the right amplifier 36 between the junction points 166 and 161 and the entirety of the charge from the capacitor C-13 is conveyed into the capacitor C-1.

When the shaft 62 moves the next step to the "n" position, capacitor C-14 then takes the position of capacitor C-23 of Figure 3 and discharges into capacitors C-1 and C-2 by reason of connections arrived at and in the same manner as described above. In this manner, the apparatus moves through the second half of the first cycle of operation, subject to the taking of an output at a selected location as described below.

Selecting and totalling output signals

Assuming that an output is to be taken in position "o" from capacitor C-15, it is now desirable to move the description back one step, which in this case refers to the position "n." When the switch 50 entered into the position "n," it did so under the impelling of the spring 78 and the electromagnetic device 79, which includes the energizing means for the relay 234, was de-energized. However, because it was necessary to re-energize the spring 78 prior to entrance of the switch 50 into its "o" position, said electromagnetic device 79 had to be re-energized prior to entry of the switch 50 into its "o" position. Thus, in order to effect a conducting of charge into the output apparatus (particularly referring to the output amplifier 181 and the output capacitor C-26) in the "o" position, the necessary switching for this must be effected while the switch 50 is in its "n" position. Thus, the output selection switch 264 will be set in its fourth position, that is, for effecting closure of the circuit for making connection between the movable contact member 64d and the conductor 262 in the position "n" of the switch 50. With the selection switch 264 so set, as shown in Figure 9a, for contact with movable contact member 64d to effect output from capacitor C-15, this will, at position "o" in the second half of the first cycle, divert the right-hand (Figure 1) branch of output from capacitor C-15 into the accumulation portion of the circuit rather than into further dividing and redividing relationships provided in the capacitors C-1 to C-25, inclusive.

In this position the positive side of capacitor C-15 will be connected to ground through movable contact member 64i and its negative terminal will be connected through the movable contact member 64j to the junction point 157 and hence through the divider 27-2 and through selectable terminals 53o and 54o to the fixed terminals 53z and 54z, respectively. However, with the output selection armature 263 in its fourth position as described above, energizing of the electromagnetic device 79 during the "n" position of the apparatus in preparation for moving the switch into its "o" position will close the lower armature 248 of the relay 234 against its contact 244 and effect connection from the source S-10 through winding of the relay 173 to the junction point 251 and thence by the conductor 249 through the lower contact 244 of the relay 234 to the junction point 246, thence to the junction point 261 and through the conductor 262 to and through the movable contact member 64d of the switch 50 and thence through the fixed terminal 55z to ground. Thus, the upper armature of the relay 173 moves into its downward position against the contact 184 and thus connects the conductor 174 to the junction point 183 instead of its being connected to the junction point 166 as previously. Such energizing of the relay 173 also moves its lower armature 252 against

the contact 255 to make a circuit from the source S-10 through the resistance 253 to ground and thereby hold the relay 173 energized after the termination of the pulse supplied by the momentary closing of the lower contact of the relay 234. Inasmuch as the energization of the relay 234 is only momentary, as the result of only a short pulse through its winding, it will be appreciated that such a lock-in of the winding of the relay 173 will be necessary to hold this relay energized when the switch 50 moves into its "o" position.

Thus, the movement of the upper armature of the relay 173 against the contact 184 connects the rightward branch of the divider 27-2 to the output amplifier 181 and thereby to the output capacitor C-26, and the energizing of the relay 173 opens the connection of the upper contact 172 from the other branch of said divider to the right amplifier 36. Such other side of the divider 27-2, namely, the conductor 151 will be connected in the same manner as described previously, to the junction point 168. Thus, while the left amplifier will be connected as above described through the movable contact members 64h and 64g to the terminals of the capacitor C-2, the output from the capacitor C-15 that would otherwise go to capacitor C-3 will be connected to the output amplifier 181 and capacitor C-26 and any charge discharging from the capacitor C-15 through the rightward branch, conductor 149, of the divider 27-2 will be received in the output capacitor C-26 and accumulated therein.

Upon the appearance of the next pulse in the electromagnetic device 79, which will occur near the end of the period of time during which the switch 50 occupies the "o" position, and by which time the connection between the movable contact member 64d and the conductor 262 is broken, the junction point 251 is now connected by the conductor 249 through the relay 234 to the junction point 246 and thence through the relatively low resistance 247 to the source S-9. Said resistance 247 being of much lower impedance than that of the winding of the relay 173, the potential of the junction point 251 will be diminished to such a level that the current flowing through the said last-named winding decreases to a value less than that required for holding the relay 173 energized. Accordingly, said relay becomes de-energized and the armatures thereof return to the positions shown in Figure 9b. Hence, the next output from whichever of the right-hand ends of the divider circuits 27-1 and 27-2 is connected for operation at a given moment will, as before, be directed into the right hand amplifier 36 and to the capacitor connected thereto in a manner above described instead of to the output amplifier 181 and output capacitor C-26.

Thus, the diversion of output from the right-hand ends of the divider circuits may be caused to occur at whatever point desired, and will occur at the same point of each cycle of operation of the apparatus, but it will occur at only one point in said cycle and the apparatus will then immediately return to the normal operating condition.

The successive actuations of the switch shaft 62 will cause the movable contact members 64 to continue successively contacting the remaining ones of the selectable terminals throughout the remainder of the cycle but in this illustration they will have no function.

As the apparatus moves through subsequent cycles of the computing procedure, the movable contact members 64 will again enter the "n" position and again contact the right-hand branch mechanism, that is, the mechanism connected to the right-hand amplifier 36, to the output amplifier 181 and the output capacitor C-26, in the manner above described in detail. Thereafter, as the movable contact members 64 enter into the "o" position, the charge on the capacitor C-15 will be conveyed into the output capacitor C-26.

While the preceding discussion has been in terms of

the output appearing in the position "o" of the switch 50, it will be recognized that this operation can occur in any other position of the switch 50 and the operation of the apparatus will be understood accordingly.

Since the meter 135 is in constant connection with the output capacitor C-26, it will provide a continuous reading of the charge in said output capacitor at all times. Thus, the operator may watch the cycle counter 217 and the meter 135 and determine readily and rapidly the amount of output at the end of each cycle of operation obtainable with any given setting of the dividers 27-1 and 27-2 and may permit the computer to run through as many cycles of operation as appears feasible. Eventually, however, substantially the entirety of the charge originally applied to capacitor C-1 will appear in the output capacitor C-26 and continued running of the apparatus through further cycles will not add appreciably to the charge on the output capacitor. This corresponds to the running of successive cycles in a fractionating operation after substantially all of the material "A" being investigated has appeared in the output and has been received into the accumulation container.

Terminating the computing procedure

Assuming now that sufficient cycles of operation have been carried out and that no further appreciable charge is being added to the output capacitor C-26 by continued operation of the apparatus, the operation is ready to be terminated. This may be done by closing the switch 224. Inasmuch as the only connection of the switch 224 is to the home position in row or switch level 55 of the terminal switch 50, the apparatus will continue through its operation until the movable contact member 64d contacts said home position 55H. This, then, will in the manner above described reduce the potential at junction point 221 to ground potential and will stop further operation of the electromagnetic device 79, thereby stopping step wise rotation of the switch shaft 62.

Alternatively, the apparatus may be stopped immediately in whatever position it happens then to be located by closing the switch 257. This grounds the junction point 239 and thereby energizes the winding of the relay 234, which opens its upper contact 233, thereby preventing further charging of the capacitor 227. If, however, the apparatus is stopped in a position in which it is not desired to have it remain, it can be stepped manually by repeated actuations of the switch 257 which will repeatedly energize the electromagnetic device 79 and thereby step the apparatus in the same manner as occurs by reason of the successive pulses derived from the apparatus associated with the capacitor 227.

It will now be desirable to make sure that all of the charge originally applied to the capacitor C-1, and now primarily appearing in the output capacitor C-26 but also scattered in minor amount in numerous others of said capacitors C-1 to C-25, inclusive, is gathered as much as possible into the output capacitor C-26. This will be accomplished by the depression of the scavenger switch 214. Closing of this switch will make a connection from the source S-5 to ground and will thereby energize the winding of the relay 177. Such energization will open the connection of the upper armature with the contact 176 and will close the lower armature 206 against the contact 211. Opening the contact 176 disconnects the left-hand amplifier 39 and whatever capacitors are at any given moment connected thereto. Closing the contact 211 will make a connection from the source S-10 through the conductor 249, through the lower contacts of the relay 234, when same are closed, to the junction point 261 and thence by the conductor 212 and through the contact 211 of relay 177 to ground. This brings the upper armature of relay 173 against the contact 184 and connects the right hand branches of both di-

viders to the output amplifier 181 and output capacitor C-26.

Thus, as the apparatus goes through one further cycling of the movable contacts 64, usually by manually and repeatedly closing the switch 257, against all of the selectable contacts of the switch 30, all of the capacitors C-1 to C-25, inclusive, at one time or another are connected to discharge all of their remaining charge into the capacitor C-26. Thus, the residual energy remaining in all of said capacitors may be determined, and the total energy in the output capacitor C-26 may be compared to the total energy originally applied in capacitor C-1 and the error, if any, developed in the computation provided by the apparatus herein described may be also ascertained. In this way, substantially all of the charge originally applied to the capacitor C-1 is accounted for and the error can be dealt with in whatever manner appears proper. Thus, the machine is not only held to an extremely low error as described above, but it also is possible to ascertain what error does exist and to make whatever disposition of it seems appropriate in the evaluating of the final result.

Thus, this invention not only provides a machine of a high degree of accuracy and reliability, but one in which the degree of accuracy of the answer obtained by any given computation is known within very close limits of accuracy so that the apparatus is substantially self-checking.

With the scavenger switch 214 remaining closed, the relay 177 will remain energized and thereby energize the winding of the relay 173 with each energizing of the relay 234 so that the scavenging condition above described will occur each time the switch 257 is closed and discharge of the capacitors C-1 to C-25 into the output capacitor C-26 will occur without regard to the functioning of the source S-9 in a manner above described in connection with the normal taking of an output at a selected point during the regular course of a computation.

Discharging the output capacitor

The capacitor C-26 may be discharged by closing switch 202. This will connect source S-4 through the winding of relay 196 to ground and will thereby energize said relay. Closing the armature of relay 196 against contact 197 will cause a portion of the output voltage of amplifier 181 to be impressed on its input terminal thereby causing the output voltage to approach zero. This will effect a discharge of capacitor C-26.

The capacitor C-26 may be discharged at the end of a series of calculations. Alternatively, in some type of calculations after a number of cycles have been performed the increments of charge added to capacitor C-26 as the result of an output from a single stage are so small that it is difficult to determine the exact amount of such increment. Under such circumstances, it is advisable to discharge the capacitor C-26 completely before such increment is added thereto and thereafter transferring the increment to the capacitor. Usually it will be advisable to switch the meter 135 from its high range setting to the low range setting so that the value of the increment may be more readily determined. Further, complete discharge of the capacitor C-26 is used in order to properly calibrate the amplifier and meter.

Therefore, the apparatus may be arranged to simulate a variety of different operating conditions in a series of extraction steps and the machine will very quickly determine the output at specified points in connection with such steps. More particularly, with the percentages above set forth by way of example, the machine will quickly determine the output available for a desired number of stages at the end of any selected number of cycles and the operator can then determine the optimum number of such cycles to operate in view of the particular economics of the process being employed. Then, for further analysis, the stages can be increased as desired and corresponding computations performed to determine

the economics of utilizing more stages of extraction with less than, more than, or an equal number of cycles than was carried out in the first selected operation. Still further possible calculations will be found in the use of a variety of different divisional ratios in the divider portion of the unit, either as a single ratio for all stages or as two or more ratios for differing numbers of stages. This latter may also include the application of a first ratio to one or more stages, another ratio to the next subsequent stages and then again utilizing the first ratio for the balance of the stages.

While the preceding paragraph does not attempt to exhaust all of the possible permutations and arrangements by which the extraction operation can be carried out, it is sufficient to suggest the extremely large number of calculations which may be required to determine the optimum operating conditions for a given extraction procedure and all of which calculations the above described computer is capable of carrying out in a matter of only a few seconds or minutes each. Thus, it will be apparent that the computer of the present invention will enable the operator to determine in a matter of minutes the optimum operating conditions for a given extraction procedure under circumstances where to carry out the computations manually would require days, weeks and even months of time.

MODIFICATIONS

Throughout the foregoing description of the construction and operation of a specific device embodying the present invention, it has been assumed that the electrical characteristic being handled is a charge imposed on a capacitance and such is preferable for the specific use here intended. However, it will be readily understood that other electrical characteristics, such as a voltage, could alternatively be used, particularly for other possible uses having different specific requirements. For example, where greater cumulative error can be tolerated, as where only a few, as four or five, operations are being performed and where greater flexibility in the charging of the receiving capacitors (corresponding to capacitors 38 and 40 in Figure 3) is required, then a modified basic circuit may be used of the type shown in Figure 10.

From an examination of said circuit, and by comparison of Figure 3 with Figures 9a and 9b above, the manner of utilizing the basic circuit of Figure 10 for creating a detailed circuit corresponding to Figures 9a and 9b will be evident to one skilled in the art.

Turning now to Figure 10, a source S is connected across terminals 301 and 302 for initially charging a capacitor 303. A D.C. amplifier 304 is connected in parallel with said capacitor 303, its input terminal connected to terminal 302 and its output terminal connected to terminal 301. A divider circuit 305 includes a conductor 306 connected to the output of the D.C. amplifier and also includes a pair of potentiometers 307 and 308, which are connected in parallel with respect to each other between the conductor 306 and ground. The sliders 309 and 310 of said potentiometers are respectively connected through second and third capacitors 311 and 312 to ground.

With an initial charge placed on the capacitor 303, the potential ratio between the input and output of the D.C. amplifier is the same as the voltage across the capacitor 303. Thus, the potential at the amplifier output with respect to ground is supplied by the amplifier but its value is determined by the voltage across the capacitor. Closing the switch 313 supplies said voltage to the conductor 306 and to the potentiometers 307 and 308. Said potentiometers are adjusted as desired, usually oppositely with respect to each other, in order to charge the capacitors 311 and 312 in the relative proportions desired, but still having the total of the voltages across the capacitors 311 and 312 either equal to, or bearing predetermined relationship with, the voltage across the

capacitor 303. The switch 313 will then be opened and any convenient means, not shown, applied to discharge capacitor 303.

The manner by which the basic circuit shown in Figure 10 can be developed into a complete circuit for operating an appropriate computer will be evident to those skilled in the art by observing the manner in which the basic circuit shown in Figure 3 is developed into the circuit appearing in Figures 9a and 9b. Accordingly, it is believed that further detailing of this modification is unnecessary.

While the apparatus of the present invention was specifically designed for carrying out the computations involved in a chemical extraction process, it will be apparent that a large number of other types of operations also involve the dividing out of portions of a mass, such as in mineral purification or atomic energy calculations. The computer of the present invention is readily applicable to such other situations, both without modification or with such modifications as will be obvious in the light of the foregoing discussion for meeting the requirements of the particular problem at hand.

While a specific embodiment of the invention has been here utilized to illustrate said invention, and only a few modifications indicated during the course of this description thereof, it will be apparent that many other modifications may be made in the apparatus, particularly with respect to the number of stages provided, character of the switch apparatus, and details of the various switching and control devices provided, and all will be within the scope of the hereinafter appended claims excepting as said claims by their own terms expressly require otherwise.

I claim:

1. A circuit for predicting the quantity of a selected material which is separable from a mixture including said material by successive fractionating steps effecting successive extractions of selected proportions of said material from said mixture, comprising the combination: a first storage device, and means for supplying same with a measurable electrical charge; second and third storage devices; circuitry including a divider having its input terminal connected to said first storage device and having its output terminals connected to said second and third storage devices; means associated with said second and third storage devices for maintaining a sufficiently low potential on the input side of said second and third storage devices to insure substantially complete discharge of said first storage device; further electrical storage devices and means connecting same to each other and to said first, second and third storage devices for establishing a charge on and discharging such storage devices in a pattern corresponding to the movement of said selected material through said fractionating operation; an output charge storage device receiving increments of charge at selected points through the total operation; and means indicating the total amount of charge accumulated in said output energy storage device.

2. The circuit defined in claim 1 wherein said circuitry includes a step-wise operating switch having a plurality of input terminals and having also a plurality of groups of output terminals, each group being associated, respectively, with one input terminal, and means connecting the terminals of the storage devices to the output terminals in the groups in such fashion that when corresponding ones of said output terminals in the respective groups are connected to the input terminals for the groups, selected ones of the storage devices are connected to the input terminals for being charged or discharged by potential applied thereto, said switch also having means for connecting said input terminals to successive ones of said output terminals for successively connecting selected ones of said storage devices to the input terminals of said switch.

3. The circuit defined in claim 1 including a pair of

D.C. amplifiers arranged, respectively, in parallel around said second and third storage devices, each of said amplifiers having its input terminal connected to the input side of the storage device connected in parallel therewith.

4. A circuit for predicting the quantitative relationships obtainable from a plurality of successive fractionating procedures, comprising in combination: first, second and third capacitors; means for charging said first capacitor; a current divider; circuitry connecting such first capacitor through said current divider to said second and third capacitors for establishing predetermined proportions of said charge on said first capacitor on said second and third capacitors, respectively; said circuitry further including impelling means for substantially fully discharging said first capacitor simultaneously with the establishing of charges of said proportions on said second and said third capacitors; a fourth capacitor; switching means for substantially entirely discharging said second capacitor and simultaneously establishing a charge on first capacitor equal to the charge on said second capacitor; means for substantially entirely discharging said third capacitor and for simultaneously establishing charges on said first capacitor and said fourth capacitor, which charges have a predetermined ratio with respect to each other and which total the charge on said third capacitor, said switching means for discharging said second and third capacitors including said impelling means for effecting substantially complete discharge of said second and third capacitors; accumulator means; counting means responsive to the number of times a given portion of the circuit is energized for directing the discharge of a selected capacitor into said accumulator means; and means for measuring the total charge in said accumulator means.

5. The circuit defined in claim 4 wherein the circuitry through which the second and third capacitors discharge simultaneously with the establishment of a charge on said first capacitor is the same circuitry into which said first capacitor discharges simultaneously with the establishment of a charge on said second and third capacitors and, further, wherein the circuitry by which the third capacitor discharges back simultaneously with the establishment of charges on the first capacitor and the fourth capacitor is the same circuitry by which the first capacitor discharges simultaneously with the establishment of charge on the second and third capacitors; and switching means for serially connecting a capacitor being discharged at any given time through the said circuitry to the capacitors on which a charge is being established.

6. The circuit defined in claim 5 wherein said switching means is a switch having an armature, a series of input terminals connected to said circuitry and a plurality of groups of output terminals, each group of said output terminals being associated with one of said input terminals and each of said output terminals being connected to selected ones of said capacitors, whereby step-wise operation of the armature of said switch will connect input terminals and the charge transferring circuitry associated therewith to selected ones of said capacitors.

7. Circuitry for discharging substantially the entirety of a charge from a first capacitor into a second capacitor, comprising: means connecting said first capacitor to said second capacitor, said first capacitor being free from any connection to a discharge circuit other than through said second capacitor; a D.C. amplifier connected in parallel with said second capacitor, the input terminal of said amplifier being connected to the input side of said second capacitor and the output terminal of said amplifier being connected to the opposite side of said second capacitor and also being connected to ground whereby so long as there remains any appreciable voltage with respect to ground on the conductor between said first and second capacitors, there will be provided on said opposite side of said second capacitor a very high voltage and thereby draw the potential on the input side

of said second capacitor to a very low value and thereby effect substantially a complete discharge of said first capacitor.

8. A computing apparatus for providing an electrical analogy to the operation of a fractionating column, comprising the combination: first, second and third capacitors and an output capacitor; first and second D.C. amplifiers; a switch including a plurality of output terminals and having a plurality of groups of input terminals, each of said groups being respectively arranged for operation in conjunction with one of said output terminals, and step-wise propelling means for connecting said input terminals in the respective groups successively with the output terminals; means connecting the input terminals of each of said D.C. amplifiers to selected ones respectively of said switch output terminals and other means connecting the respective output terminals of said D.C. amplifiers to others of said switch output terminals; a divider circuit and means connecting the input of said divider circuit to an output terminal of one of said groups; a ground connection and means connecting said ground connection to selected ones of said output terminals; means connecting the output conductors of said divider circuit each respectively to an input terminal of said switch and means connecting the selected ones of output terminals corresponding to said last named input terminals respectively to the input ends of said amplifiers; output switching means for diverting the output from one of the output conductors of said divider to said output capacitor and counting means responsive to the position of said switch with respect to output terminals within one of said groups for actuating said output switching means; means charging the first of said capacitors to a predetermined value; and means for measuring the charge at a given time on said output capacitor.

9. A circuit for dividing a charge which includes a first capacitor; a divider; means connecting one of the terminals of said first capacitor to ground and means connecting the other terminal of said first capacitor to the input terminal of said divider; a plurality of D.C. amplifiers; means connecting each output terminal of said divider to the input terminal of one of said amplifiers, said last-named means including a switch; a plurality of receiving capacitors; means connecting one terminal of each of said receiving capacitors to the input terminal of one of said amplifiers and connecting the other terminal thereof to the output terminal of said one amplifier; and means for maintaining the potential at the input terminals of said amplifiers substantially at ground.

10. A circuit according to claim 9 including an adjustable inductance between said one terminal of said first capacitor and ground; a resistance between the other terminal of said first capacitor and said divider; said inductance and said resistance being part of a critically damped circuit so that the discharge current from said first capacitor will reach its maximum a predetermined time after initiation of discharge therefrom and will thereafter decrease to zero in a short time.

11. A circuit for dividing a charge which includes: a plurality of capacitors so arranged that certain of said capacitors are charged while others of said capacitors are capable of being charged; a plurality of D.C. amplifiers; a divider circuit; switch means for simultaneously connecting a charged capacitor to the input terminal of said divider circuit and for connecting each of the output terminals of said divider, respectively, to the input terminal of an amplifier and for connecting a terminal of an uncharged capacitor to the input terminal of such an amplifier and for connecting the other terminal of such uncharged capacitor to the output terminal of such amplifier.

12. A circuit according to claim 11 including an output D.C. amplifier; an output capacitor having one terminal connected to the input terminal of said output

amplifier and its other terminal connected to the output terminal of said output amplifier; said switch means connecting one output terminal of said divider to the input terminal of said output amplifier at selected times during the cycle of operation thereof.

13. A computer circuit which includes: a first series of capacitors; means for placing an initial charge on at least one of said first series of capacitors; a second series of capacitors arranged to have a charge established thereon upon discharge of the charged capacitors in said first series; a pair of D.C. amplifiers; a divider circuit having an input and two output terminals; switch means for successively connecting the capacitors in said first series to the input terminal of said divider circuit and for simultaneously connecting each of the output terminals of said divider circuit to the input terminal of an amplifier and for simultaneously successively connecting the terminals of the capacitors in said second series to the input and output terminals of said amplifier, said switch means being operable to successively discharge all of the capacitors in said first series and to successively establish a charge on the capacitors of said second series and thereupon being operable to reverse the connections of said first and second series of capacitors whereby said second series of capacitors may be successively discharged and said first series of capacitors may be charged.

14. A computer circuit which includes: a first series of capacitors; means for placing an initial charge on at least one of said first series of capacitors; a second series of capacitors arranged to have a charge established thereon upon discharge of the charged capacitors in said first series; a pair of D.C. amplifiers; a pair of divider circuits, each divider circuit having an input and two output terminals; switch means including armature means for respectively connecting and disconnecting said first and second series of capacitors with said amplifiers and divider circuits; said switch means including a first group of terminals, at least one of said first group of switch terminals being connected to one output terminal of one of said divider circuits and the remainder of said first group of switch terminals being connected to a corresponding output terminal of the other of said divider circuits; a second group of switch terminals, corresponding terminals of said second group of switch terminals being connected, respectively to the other output terminals of said divider circuits; said armature means successively connecting the terminals of said first and second groups of terminals to the input terminals of said amplifiers; third, fourth, fifth, sixth, seventh, and eighth groups of switch terminals, said third and fourth groups of switch terminals being connected to the positive and negative terminals of said first and second series of capacitors, said armature means successively connecting the terminals of said third and fourth groups, respectively, to the input and output terminals of one of said amplifiers; said fifth and sixth groups being connected to the positive and negative terminals of said first and second series of capacitors, said armature means successively connecting the terminals of said fifth and sixth groups, respectively, to the input and output terminals of the other of said amplifiers; said seventh and eighth groups of terminals being connected to the positive and negative terminals of said first and second series of capacitors, said armature means connecting the terminals of the seventh group to ground and connecting the terminals of the eighth group to the input terminal of each of said divider circuits whereby a charged capacitor in said first group is connectable by its terminal in the eighth group to the input terminals to the divider circuit and is connectable from the output terminals of said divider circuits through the first and second group of contacts to the input terminals of the amplifiers and wherein the capacitors to be charged in the second group are connected in parallel with the amplifiers through the terminals in the third, fourth, fifth and sixth groups, the terminals in the third through eighth groups being so

arranged that a capacitor in the first series is being discharged while two capacitors in the second series are being charged.

15. A computer circuit according to claim 14 including a ninth group of switch terminals; an output selection switch connectable through a selected one of said ninth group of switch terminals and through said armature means to ground; an output amplifier; an output capacitor whose terminals are connected to the input and output terminals of said output amplifier, means operable upon connection of said output selection switch to ground to connect the armature means engaging one of said first and second groups of switch terminals to the input terminal of said output amplifier.

16. A computer circuit according to claim 15 including a scavenging switch and means operable by actuation of said scavenging switch for diverting substantially all of the charge remaining in said first and second series of capacitors into said output capacitor upon continued cycling of said armature means.

17. An apparatus for predicting the quantitative relationships obtainable from a plurality of successive fractionating steps, comprising: a first storage device and means for storing in said first storage device a measurable electrical charge representing the original quantity of the material being separated; second and third storage devices; means for resolving the electrical charge in said first storage device into proportions equal to the proportions derivable from a step in the fractionating operation being investigated and establishing substantially the entirety of said electrical charge as so resolved respectively on said second and third storage devices; means for resolving the electrical charge on said second and third storage devices and establishing same on further storage devices in a manner analogous to the fractionating steps; and means for measuring the electrical charge in selected storage devices representing desired points in the fractionating operation in order to obtain an indication of the output of a selected fractionating operation.

18. An apparatus for simulating the behavior of a quantity that is to be subjected to a series of successive division and combination operations, comprising: a plurality of first storage devices and means for establishing a charge representing a predetermined percentage of said quantity on each of said first storage devices; a plurality of further storage devices; means for discharging said first storage devices and dividing the charge on each thereof and establishing portions of said charge on further storage devices, said portions of said charge established on said further storage devices from one of said first storage devices being proportional to the division of the quantity in a given division operation, said last-named means including means for adding to each of said further storage devices a further charge corresponding to a portion of the charge from another of said first storage devices and combining both charges so that the charge on each of said further storage devices comprises portions of the charges from two of said first storage devices; a series of further storage devices and means for further dividing and combining the charges on the storage devices to simulate further division and combination operations; and means for measuring the amount of a portion of the charge after a division operation from a selected storage device to thereby determine the amount of said quantity that would be present in the product of a division operation after a selected number of division and combination operations.

19. An apparatus for simulating the behavior of a quantity that is to be subjected to a series of successive division operations comprising: a first storage device and means for storing an electrical charge corresponding to said quantity thereon; means for discharging said first

storage device and dividing the entirety of said charge into two portions proportional to the division of said quantity in a first division operation; a first pair of storage devices and means for establishing said portions of said charge, respectively, on said first pair of storage devices; means for discharging said first pair of storage devices and dividing the charge on each of said first pair of storage devices into two portions proportional to the division of said quantity in a further division operation; a second pair of storage devices and means establishing one of said last-named portions as a charge on one of said second pair of storage devices and establishing the other of said last-named portions as a charge on the other of said second pair of storage devices; a series of further pairs of storage devices and means for repeatedly dividing and establishing charges on said further pairs of storage devices so that at least one storage device in each series is charged corresponding to a portion of a charge on one storage device in the preceding series; and means for measuring the amount of a portion of the charge on a selected storage device to determine the amount of said quantity that would be present in a corresponding one of said series of division operations.

20. An apparatus for simulating the behavior of a quantity that is to be subjected to a series of successive separation operations comprising: a first series of storage devices and means for establishing a charge on at least one of the first series of storage devices; circuitry for successively receiving the charges from the first series of storage devices and successively separating each of same into portions bearing the same ratio with respect to each other as do the products of corresponding stages of separation operations; a second series of storage devices and circuitry for successively establishing charges corresponding to said portions on successive ones of the second series of storage devices and simultaneously successively reducing the charge on said first series of devices to zero; circuitry for successively receiving the charges from the second series of storage devices and separating each of said charges into further portions bearing the same ratio to each other as to the products of separation operations during a second cycle thereof; a third series of storage devices; circuitry for establishing said portions from said second series of storage devices on a third series of storage devices while successively reducing the charges on the second series of storage devices to zero; further series of storage devices and circuitry for separating charges on said series of storage devices into portions and establishing said portions on storage devices in the following series until the desired number of cycles of separation operations has been simulated; and means for measuring charges corresponding to portions separated during a given stage in successive cycles to determine the amount of said quantity which is separated at the same stage in successive cycles of the separation operations.

21. An apparatus according to claim 20 including circuitry for combining portions of the charge from two storage devices in one series and establishing same on a storage device in the succeeding series.

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