that animals appear to "learn" that the activation of the muscle being used is necessary to operate the electronic control; at least there is observed to be improvement in the process with use, in any individual experiment.

A sufficient number of experiments upon dogs have been performed to prove the efficacy of the device in allowing the animals' neurological and biochemical mechanisms to control their own respiratory needs. Through the electronic control, the animals used in the experiments made very rapid readjustments and quickly regained relatively normal blood values after the experimenter had by interference brought about for brief intervals extreme stages of hyper- and hypoventilation (*4*).

To date, experience with patients has been confined to testing the apparatus on partially paralyzed individuals who could stay out of a respirator for part of a day and who were interested in cooperating with the investigation. These patients have relied upon the electronic control for their respiration for periods of more than 24 hours at a time while under constant observation. This included long periods of normal sleep. During the time of use it was not necessary to adjust the skin electrodes or the controls of the electronic circuit.

The apparatus has been successfully used in both patients and animals to control pressure in tank and cuirass respirators, and to control pressure changes directly through the airway as in patients with masks and animals with intratracheal tubes.

It is obvious that this apparatus has other potentialities than its use with partially paralyzed patients. Already it has been used to map surviving muscles in such patients. As a laboratory aid in physiological research, it may be of advantage in studying problems dealing with neuromuscular function and pulmonary physiology. It offers promise of assistance in the control of inhalation anesthesia, particularly in operations in the open chest. It should be useful in the study of breathing patterns under a variety of conditions and in various diseases. It may offer aid to newborn and premature infants with respiratory distress.

References and Notes

1. This work was aided by a grant from the National Foundation for Infantile Paralysis.
2. D. McCroskey *et al.*, *Anat. Record* 124, 332 (1956).
3. An experimental unit of this type was demonstrated in July 1957 in Geneva, Switzerland, at the fourth International Poliomyelitis Conference.
4. A detailed description of these experiments is in preparation.

Integrating Device for Use with Potentiometers

W. Keith Hall, Gustave Sill, Court L. Wolfe

An automatic recording potentiometer embodies a paper chart which is driven at constant speed in the y direction. Motion in the perpendicular x direction is accomplished by a potential which is usually simply related to a quantity which varies as a function of time and whose relationship to time is of interest. If, as in the case of gas-phase chromatography, the motion in the x direction is proportional to concentration, then the integral under the traced curve is proportional to the total amount—that is,

$$\text{Total amount} = c\int_0^\infty x\,dt$$

Similar and analogous situations exist in other types of work, such as spectroscopy, where the areas are required for quantitative analysis.

The use of gas-phase chromatography in research and in process control has been undergoing revolutionary development over the past several years (*1*). In some respects, this has altered the basic approach toward research. For example, the development of the microcatalytic technique (*2*, *3*) in this laboratory has accelerated catalytic research to such a degree that measurement of the chromatograms has become the slow step. That a similar situation exists in other laboratories is evidenced by the fact that it has become almost customary to evaluate these chromatograms by simply measuring peak heights rather than peak areas, in spite of the fact that this is an approximation and one that is particularly poor in the case of broad and asymmetrical peaks. Further, as noted earlier (*3*), one of the advantages of the chromatographic technique in the study of catalytic reactions is that the experimenter can obtain semiquantitative estimates of the results of an experiment as the experiment progresses and may be guided in his choice of the next step by the results already in hand. It was readily recognized, therefore, that even this situation could be improved if actual quantitative numbers were used to replace the visual estimates. It was on this basis that the development of the instrument described in this article was undertaken. Specifications for an integrating mechanism were drawn as follows:

1) The device was to operate in conjunction with the automatic recording potentiometer available to us (Leeds and Northrup Speedomax, 5-millivolt scale).

2) It should provide for the individual integration of each peak appearing on the chromatogram as it is drawn.

3) It should read out in digital form, totalizing to at least 99,999, to be stamped on a separate tape or else on the Speedomax chart adjacent to the integrated curve.

4) It should be reproducible to better than 1 percent.

5) It should provide for automatic clearing of the stored number after printing so that the integration of the next peak or following peaks will not be cumulative.

6) The pulse output rate at full-scale deflection on the potentiometer chart must exceed 1000 counts per minute to insure a sufficient number of significant figures per unit area. This condition amounts to asking that the device be capable of producing as many significant figures as are obtainable with a hand planimeter and with an accuracy as great as that of the average of several such determinations.

7) The device should be sufficiently intelligent to be able to distinguish between meaningful data and base line noise.

To the best of our knowledge, no commercial instrument presently available fulfills all the requirements listed. It was found, however, that an instrument satisfying these requirements could be made from commercially available basic components—namely, a ball and disk integrator supplied by the Librascope

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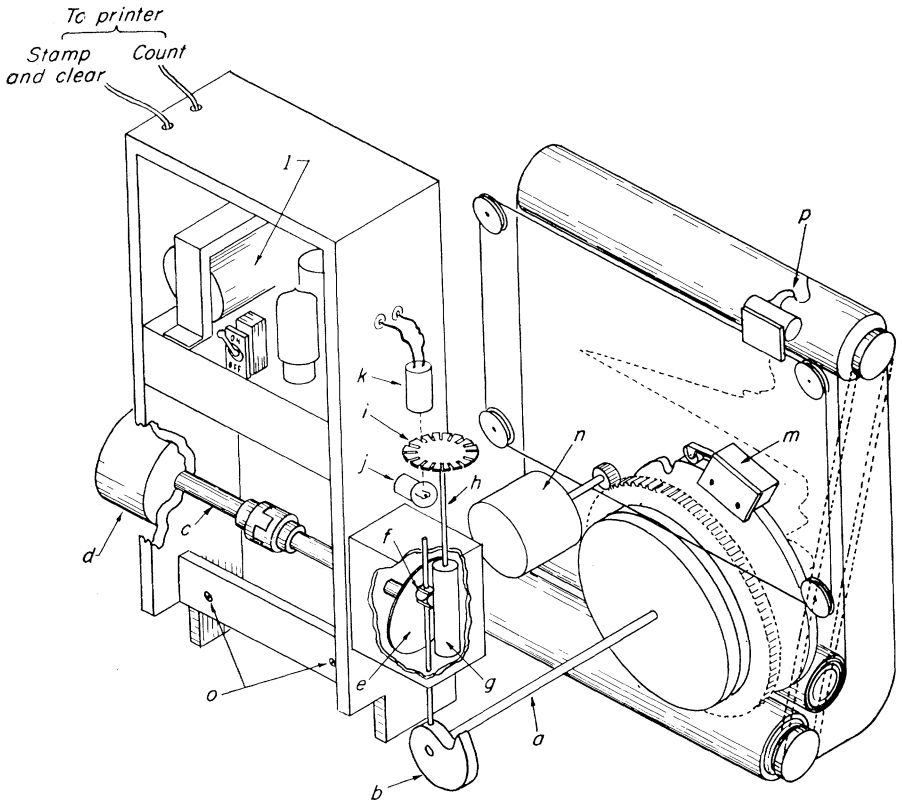

Fig 1. Schematic diagram of integrating mechanism: *a*, slide-wide shaft; *b*, linear cam; *c*, disk drive shaft; *d*, synchronous motor; *e*, disk; *f*, balls; *g*, output drum; *h*, output shaft; *i*, slotted disk; *j*, light; *k*, photocell; *l*, pulse-shaping and amplification circuit; *m*, integration base switch; *n*, balancing motor; *o*, screws holding unit to housing; *p*, pen.

Corporation; a 20-revolution-per-minute synchronous motor used to drive the integrator disk, supplied by the Hagen Manufacturing Company; and a pulse storage mechanism with a digital printout supplied by the Streeter Amet Company. To these components it was only necessary to add a linear cam made in our shops, a photoconductivity cell actuated by light passing through a slotted disk, and a conventional pulse shaping circuit, which supplied the information in a square wave form to the pulse storage mechanism. In the latter connection, it should be noted that a scaling unit ordinarily used in connection with a Geiger counter replaced the Streeter Amet pulse storage mechanism in the early developments, before the latter became available.

Operation

The operation of the device starts with the principle used on the Fisher-Gulf partitioner, but provides digital printout as well as greater resolution; it can be readily followed with reference to Fig. 1. The linear cam *b* is adjusted on the slide-wire shaft *a* in such a position that when the pen *p* is at the base line, the balls *f* are centered with respect to the disk *e* so that no motion is imparted to the output roll *g* in spite of the constant linear velocity of the disk, which is driven by the synchronous motor *d*. At this point, it is convenient to note that the rate of the rotation of the disk—that is, its radial velocity—is indirectly linked to the motion of the chart paper in the time direction, for both are driven by synchronous motors.

As the signal potential affects the balancing motor *n*, causing the pen to move in the x direction, the linear cam rotates, moving the balls out along a radius of the disk by an amount proportional to the displacement of the pen from the base line. Since the rate of rotary motion imparted to the roll by the balls, and hence the rate of rotation of the slotted disk *i*, is likewise directly proportional to the position of the balls along the radius of the disk, then the pulse rate supplied from the light source *j* to the photocell *k* is directly proportional to the displacement of the pen from the base line in the x direction.

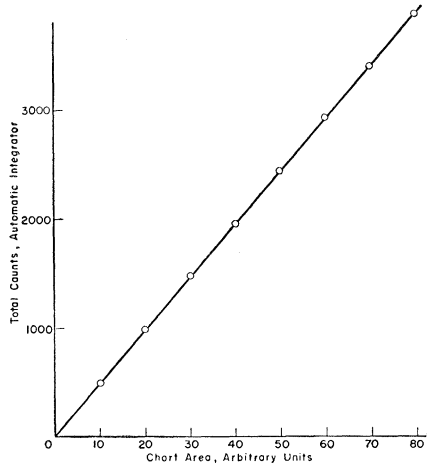

Fig. 2. Block area test of integrator.

The output of the photocell is fed into the pulse shaping and amplification circuit *l*, which is of a conventional design, but which employs a special high-speed mercury wetted relay supplied by the Western Electric Company. The output of this circuit is sent either directly into a scaling unit, in which case the summed counts are cumulative for the chromatogram and must be recorded by hand, or else into the Streeter Amet pulse storage unit until print-out is demanded by the closing of the limit switch *m* as the pen returns to the base line, when the integration ceases. Since the storage mechanism clears as it prints, areas for the individual peaks are recorded individually rather than cumulatively. In order to meet requirement 7, the limit switch *m* is positioned so that it allows the integration to begin when the pen has departed from the base line by about one-half of one division on a chart that has 100 divisions full scale and so that it allows integration to stop (and print-out to occur) under similar circumstances. (In this connection, it should be realized that a basic requirement that must be met before use of such an instrument is practical is that an extremely stable bridge circuit must be available. With the instrument described here, a set of Gow-Mac thermal conductivity cells and a conventional d-c cirucit powered by storage batteries were used. The carrying gas stream was split, and a slow purge was washed through the reference side independent of the measuring side, which was connected to the chromatographic column. With this arrangement, in a day's operation, any base line drift was within the limit of intelligence noted.)

One final comment seems justified. The linear cam faithfully produces a quantity proportional to the real area under the curve. By changing the shape of the cam, however, an automatic, mathematical transformation can be carried out. Thus for example, a logarithmic cam will produce $\int \log x \, dy$. This integral would be particularly valuable in spectroscopic work where x may be taken as I/I_0 (or log x as the optical density) and y may be taken as proportional to the wave length, λ. If the device were used

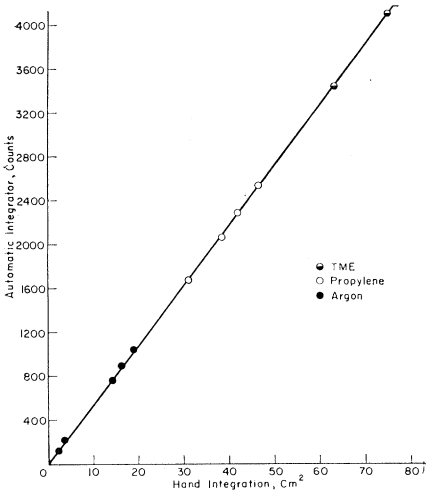

Fig. 3. Relationship between area of chromatogram and total pulse.

in this way, the analytic results could be printed out in digital form, vastly simplifying such work. It should also be noted that, if a situation should arise in which the data supplied by the integrator become a part of an elaborate and complicated calculation (as, for example, when a series of peaks from the same record are used to calculate the percentage composition of a complex mixture) then it would be possible to read out in punched-tape form, and the results could then be fed into a modern, high-speed calculating machine.

The total cost of material, labor, and so forth, exclusive of the cost of the recorder, is quite modest. This cost, however, could be reduced by a major fraction when the automatic printing and clearing features are not required. The instrument is, therefore, available to laboratories with very moderate budgets.

Accuracy and Repeatability

The accuracy and repeatability of the data are shown in Figs. 2 and 3, respectively. Figure 2 relates the number of pulses accumulated to the square area swept out on the chart; these data were obtained by using a scaling unit to totalize the number of pulses. The Speedomax was set with a millivolt source to run at a constant distance above the base line. The scaling unit and a timing clock were started and stopped simultaneously. During the elapsed time, a definite block of area was swept out on the chart as a function of the distance between the base line and the pen position. This area was plotted in arbitrary units against the total number of counts recorded in the 5-minute periods in Fig. 2. It can be seen that, on the basis of these square areas, the instrument gave perfect agreement. With the recorder used, it turned out that an arbitrary unit was nearly equal to 1 square centimeter, so that there is a close correspondence between the data plotted on Fig. 2 and on Fig. 3.

In Fig. 3, the results obtained from the automatic integrator for measurement of a number of calibration chromatograms are compared with the areas of the same peaks obtained using a B. K. Elliott hand planimeter. In these experiments, varying amounts of the several gases were passed through the column in a helium-carrying gas stream, and the response was recorded in the conventional manner. It should be emphasized that these data include results with three different gases: 2,3-dimethylbutane (tetramethylethane, or TME), propylene, and argon. The chromatographic peaks obtained for these were of vastly different shapes. The low-area argon peaks were extremely narrow and sharp. In fact, the areas are low because this gas was not held up in the column so that, even with a nearly full-scale deflection, the peak width at the base line did not exceed about 4 millimeters. The propylene peaks were still quite sharp, particularly on the front side, but were skewed by a moderately strong tail. Finally, the peaks for 2,3-dimethylbutane (TME) were very much broader than they were high. Thus, regardless of the shape of the peak, the automatic integrator appears to measure the area at least as accurately as hand integration.

This integrator can be made as an effective unit from known and available items, and we believe that its simplicity and convenience may make it useful to others.

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Automatic Particle and Bacterial Colony Counter

H. P. Mansberg

It has long been recognized that the counting of bacterial colonies on culture plates is one of the more tedious tasks performed in bacteriological laboratories. Many thousands of culture plates are counted daily in hundreds of dairy, food-industry, water-testing, pharmaceutical, and other laboratories throughout the country. In this era of electronics and automation it would appear surprising to many that automatic devices to perform this task have not been available.

Some of the standards and techniques that have evolved in bacterial assay tests are necessary compromises determined by the limitations of laboratory personnel in visual counting methods. These limitations include the inaccuracies of human counting, the inconsistencies between observers, and the high cost of both preparing and counting large numbers of samples. Quite possibly, if accurate automatic counting devices had been available before the evolution of bacterial assay standards, these standards would specify greater sampling quantities. For example, at present it is not at all unusual to find a fluctuation of 100 percent in the number of colonies from presumably identical aliquots of milk and cream (*1*). Where only one or two plates are now required by standard tests, with consequent poor sampling, the number of samples would be increased if the time and cost of preparation and evaluation were less.

Although many mechanical and visual aids have been proposed and constructed

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