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ANALYTICAL EDITION

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AMERICAN APPARATUS, INSTRUMENTS, AND INSTRUMENTATION

Ralph Holcombe Müller

Pages 571–630

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IN THE ANALYTICAL EDITION for October, 1939, we included a group of articles prepared at our request, with a view to conveying to the users of instruments and apparatus generally a better idea of the efforts made by manufacturers to meet their needs. While we are grateful to those who cooperated with us, it seemed evident that the subject matter deserved a more thorough treatment, and this we have tried to give in this issue.

Regardless of the scale upon which a chemist or chemical engineer conducts his work, all must admit that his accomplishments depend in the last analysis upon instruments and apparatus generally associated with laboratory work and their skillful use. Some of this equipment finds a place in plant operations, but the ancestry of these industrial procedures may easily be traced to the laboratory. Improvements in instrumentation therefore are important to all members of our profession.

Upon whom do we depend for improvement in such apparatus, and what progress has been made recently?

While many of the suggestions and ideas come from users, no small amount of research and development is done by the manufacturers of scientific apparatus. This means not only the development of new ideas brought to them by consumers but research carried on in their own establishments to attain definite objectives which they themselves have set.

As for the second question, it seemed best to learn this information at first hand, and we were fortunate in persuading Ralph H. Müller of New York University to visit as many plants as he could and to learn by correspondence from others something of the progress in instruments. This issue is devoted to his report. There are obvious reasons why it could not be complete, but an effort has been made to find new things as well as to discuss older ones that have proved their value in service. If something has been overlooked, it has been inadvertent and the wonder is that the coverage could be so complete as will be found in the pages that follow.

—EDITOR

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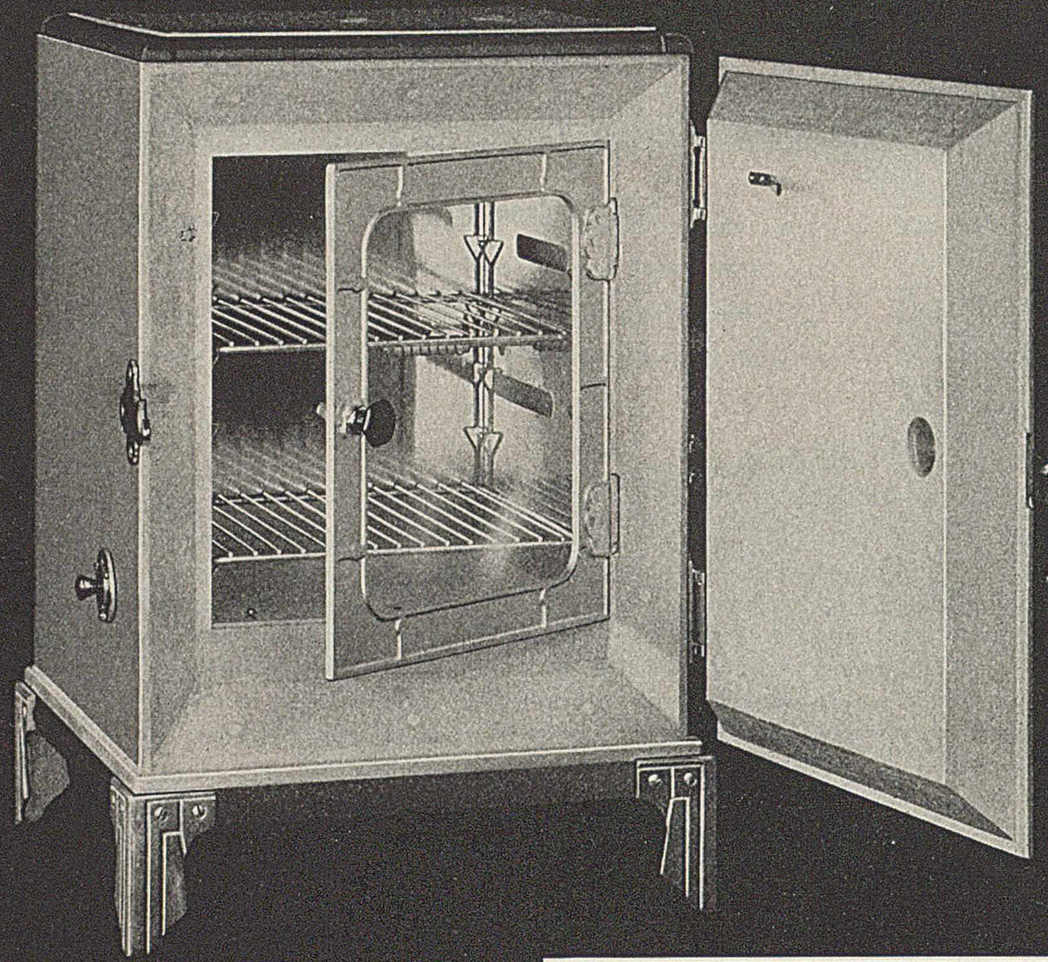

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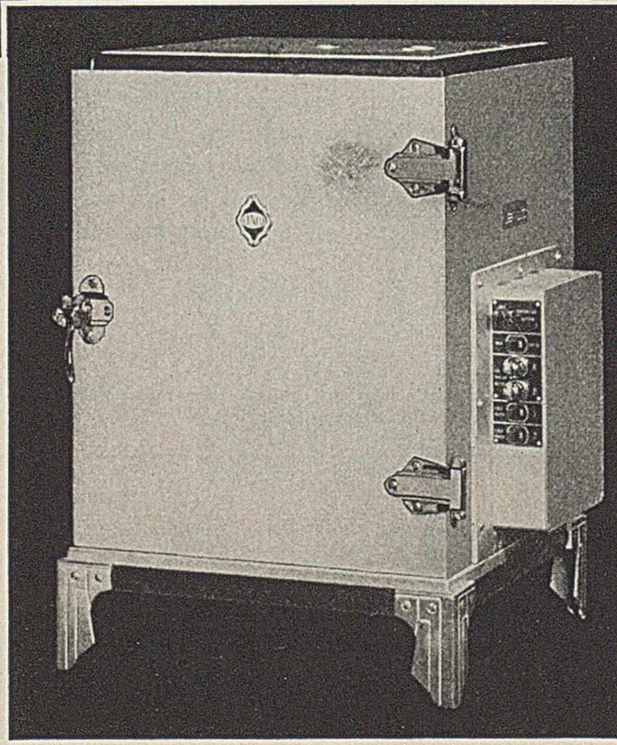

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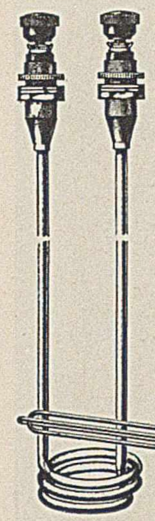

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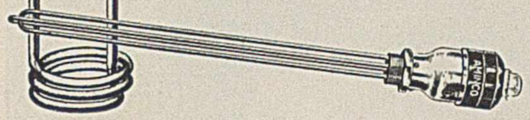

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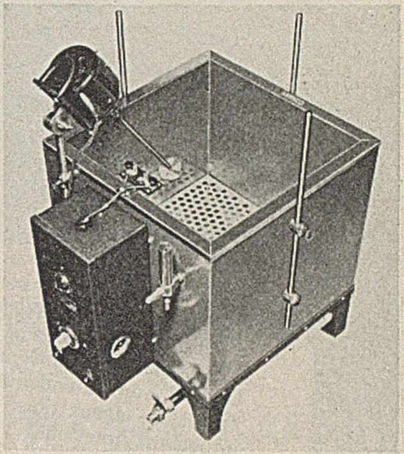

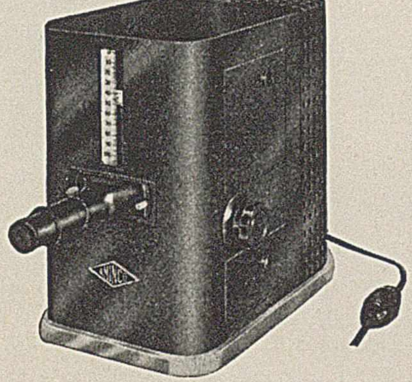

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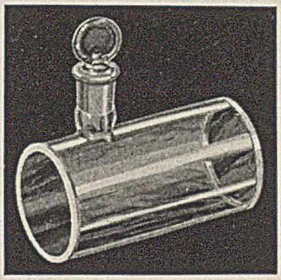

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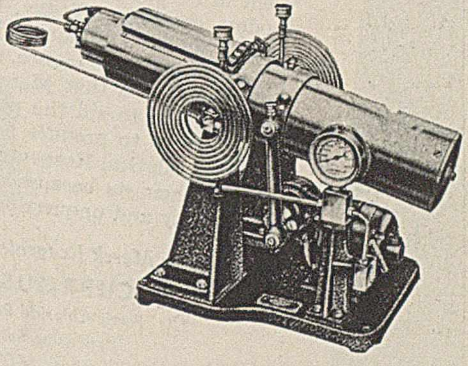

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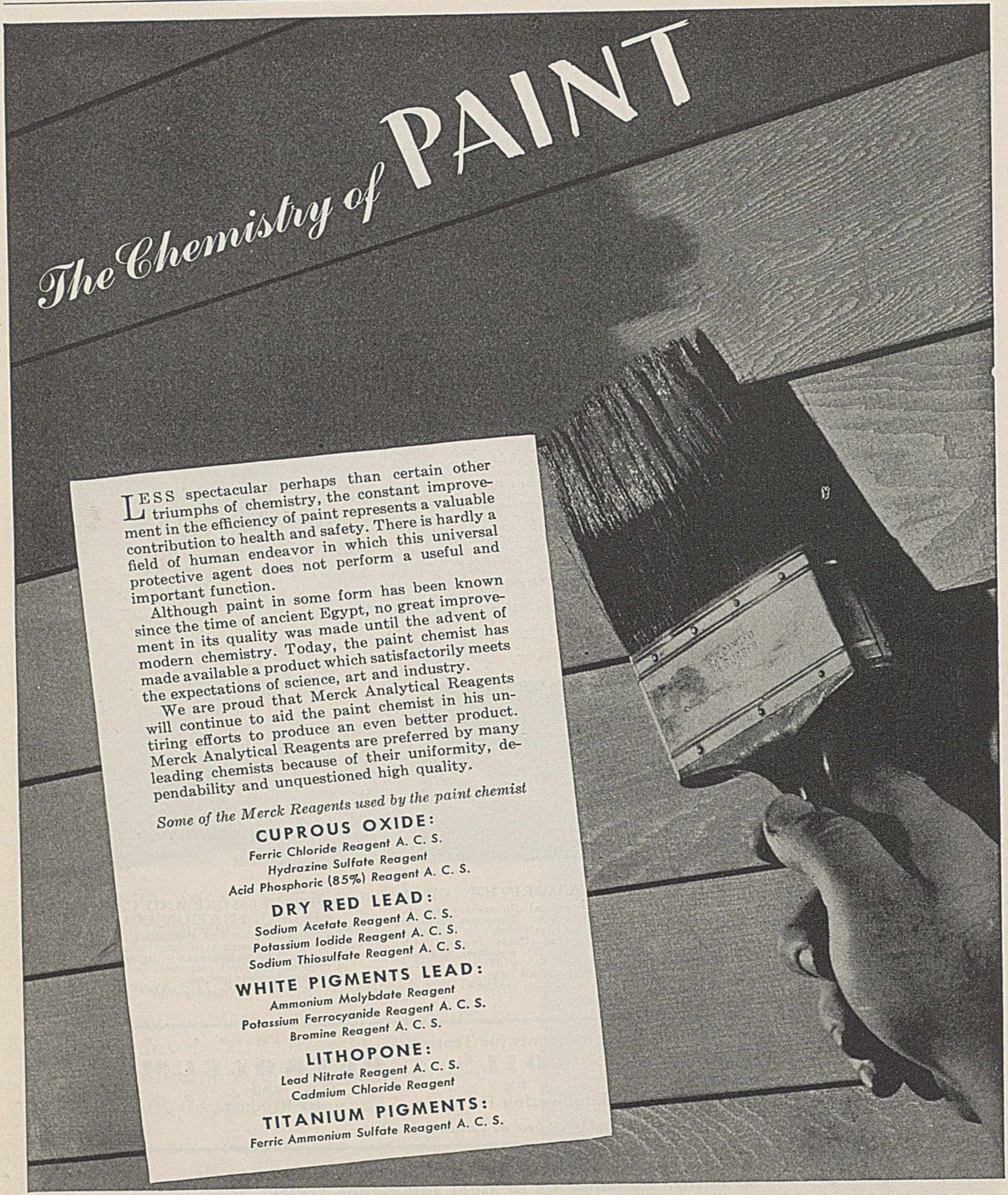
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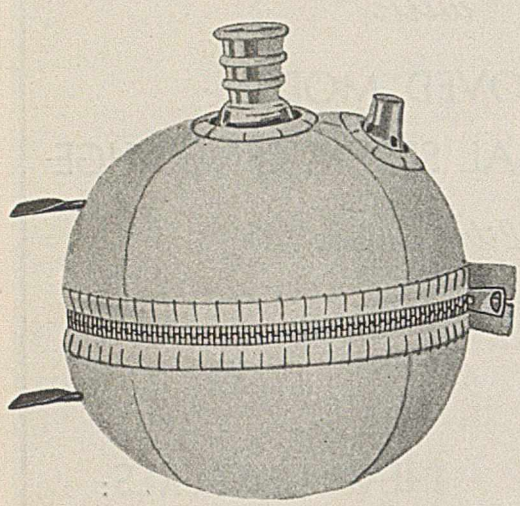

The heating of glass flasks used in distillations, digestions and extractions has always presented somewhat of a problem. Either an open flame, hot plate or liquid bath is used in the laboratory, all of these methods presenting serious fire and safety hazards, besides being inefficient.

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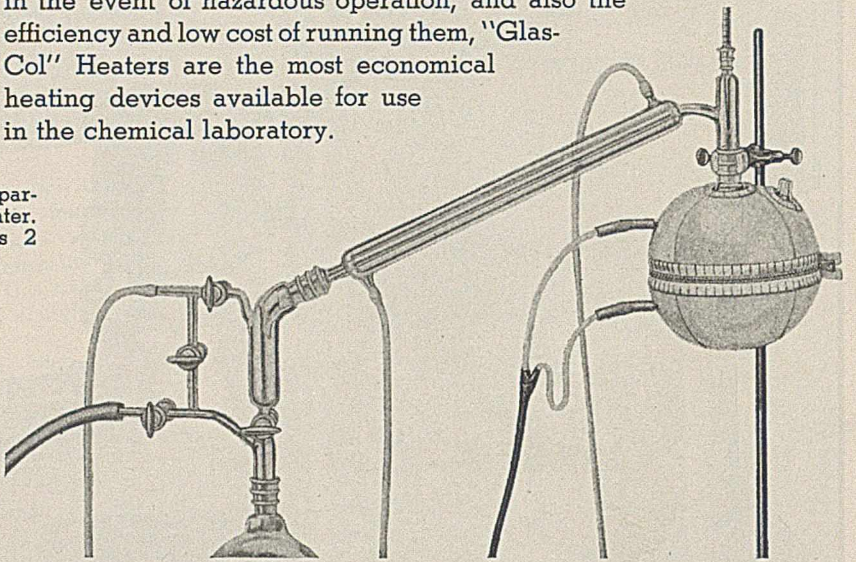
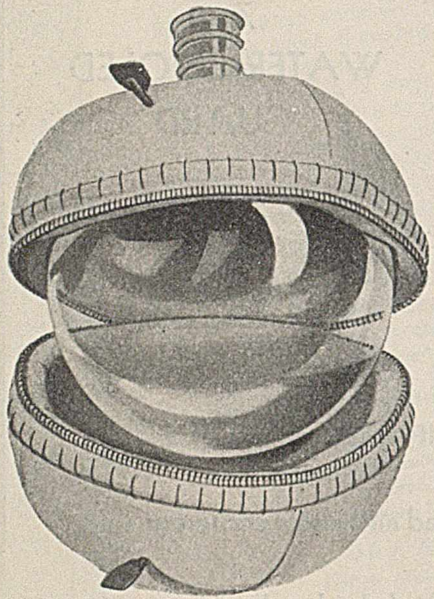


A low pressure distillation apparatus, using a "Glas-Col" Heater. Capacity of flask illustrated is 2 liters.



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11672-C	300	300		17.00
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11672-E	1000	338	112	20.00
11672-F	2000	412	138	22.50
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Capacity ml.	Standard Taper	Quantity Subject to Discount	Each
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250	24/40	12	2.00
300	24/40	12	2.25
500	24/40	12	2.50
1000	29/42	12	2.75
2000	29/42	12	3.75
3000	29/42	6	4.75
5000	45/50	6	6.75
12000	55/50	6	12.00
22000	71/60	2	24.00

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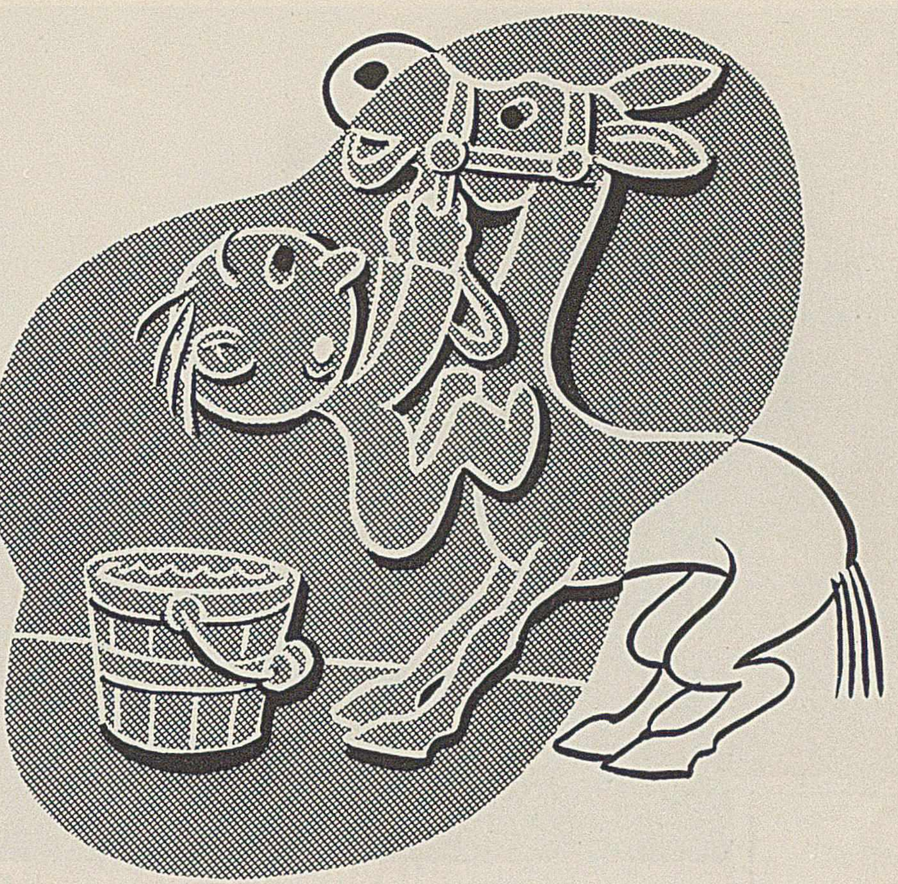

INDUSTRIAL AND ENGINEERING CHEMISTRY

ANALYTICAL EDITION

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American Apparatus, Instruments, and Instrumentation

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Department of Chemistry, New York University, Washington Square, New York, N. Y.

When your editor invited me to undertake a survey of American instruments and apparatus he was mindful of the interest which this topic aroused last year, and assured of my interest in the subject. There are many experts on instrumentation in this country who would refuse the assignment with a plea of incompetence, but there are times when one's enthusiasm conquers his better judgment. I claim some degree of expertness in but one or two of the many topics discussed in this review, and consequently every expert will bemoan the treatment of his own specialty. But someone had to do the job, and it was my good fortune to have so much good advice, and to see so much that is being done for the chemist to provide him with better equipment, that it seemed possible to get a fairly coherent picture out of the welter of detail.

It has been possible to indicate only trends and representative activities. Developments are treated according to arbitrarily selected fields of measurement and primarily those of importance for the chemist. There is not the least attempt to make comparisons of relative merit; indeed, it would not be possible for me to do so with any degree of competence in most cases.

The style is intentionally nonreportorial, since everyone can read catalogs for himself. If it inclines to the didactic, the outcroppings are not to be viewed as the uncontrollable instincts of a professor, but rather as a feeble effort to emphasize the importance of "instrumentation" as distinguished from "instruments". I have long felt that this is needed by many able chemists, who are busy doing important things and feel that there will always be enough people who are queer enough to be interested in "gadgets" to supply them with new tools when they are ready for them.

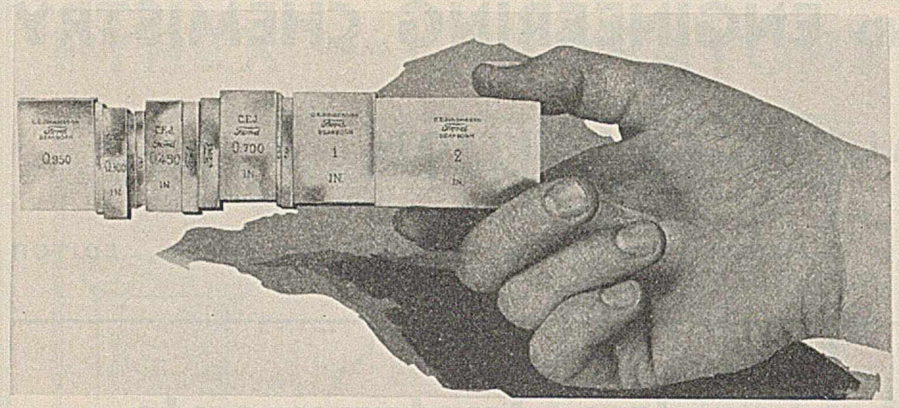
A few nontechnical aspects of the instrument and apparatus industry are discussed, in the belief that they are interesting and important. Some of them are distinctly controversial and in those cases I have adopted the role of reporter rather than commentator.

From all points of view, the privileged observer cannot fail to be impressed by the American instrument and apparatus industry. Its accomplishments are magnificent; its future is clearly defined; and its importance in the maintenance of our industrial and scientific supremacy and our national security cannot be overestimated.

THAT the history of physical science is largely the history of instruments and their intelligent use is well known. The broad generalizations and theories which have arisen from time to time have stood or fallen on the basis of accurate measurement, and in several instances new instruments have had to be devised for the purpose. There is little evidence to show that the mind of modern man is superior to that of the ancients. His tools are incomparably better. Indeed, the early philosophers disdained experiment and even common observation, if the results were contrary to sound logic. Although the modern scientist accepts and welcomes new instruments, he is less tolerant of instrumentation. He is likely to regard preoccupation with instruments and their design as "gadgeteering" and distinctly inferior to the mere use of instruments in pure research. Thus, Lord Rutherford once said of Callender, the father of recording potentiometers, "He seems to be more interested in devising a new instrument than in discovering a fundamental truth."

There are two colloquialisms which are anathema to the serious student of instruments—"gadget" and "Rube Goldberg". To some people, anything more complicated than a side-arm test tube falls in one or the other of these classifications. Some of the commonest, most widely used devices of our times are complicated beyond the comprehension of that well-known cartoonist. Anyone who seriously disagrees with this statement should throw away his wrist watch and acquire an hourglass, thus getting back to fundamentals.

Fortunately, there is a great body of earnest workers, oblivious to these jibes, devoted to these pursuits, whose



Courtesy, Ford Motor Co.

FIGURE 1. JOHANSSON GAGE BLOCKS

handiwork we may examine. They are providing means with which the "Olympians" may continue to study nature.

Instrument and Apparatus Manufacturers

The manufacture of scientific apparatus requires expensive machinery and skilled personnel. On the average staff will be found Ph.D.'s, engineers, skilled mechanics, and artisans—very little unskilled labor. Overhead in general is very high and few instruments are made in sufficient quantity to justify cost-cutting, line-production methods. In addition, the exacting demands of the business require the latest and most precise tools, which again cannot be purchased in price-saving quantities.

Development and research are important budget items, for the needs of science and industry must be studied; a new instrument must meet all the requirements of the prospective user, and in addition it must be thoroughly practical, reliable, and reasonably easy to construct and service.

After an instrument is developed and in the process of manufacture, suitable bulletins and pamphlets must be prepared, describing its operation and uses. These must be exhaustive in detail, and include pertinent literature references. Complete operating directions are necessary, and are expected even though the customer does not always read them carefully, or at least not until he has taken the instrument apart to see what is wrong with it.

The manufacturer is often required to convince the customer that the instrument will solve his problem. Very frequently, substantial proof of this is a prerequisite for the sale. Such proof often involves research on other aspects of the problem having nothing to do with the instrument itself. Many companies have a definite policy on such matters. If a new and potentially valuable application is suggested, the company will expend time and effort in studying it. If the intended application is palpably the customer's own problem and requires extensive research, he is charged for the service.

The manufacturer's costs will make the apparatus more expensive than home-made equipment. The so-called "excessive cost" of instruments and apparatus is nothing more than an honest and businesslike assay of the total costs of producing a piece of equipment, including capital investment, depreciation, material costs, decent wages, service, and sales costs. The amateur constructor does not count his time when he appraises the cost of his own handiwork.

The sales and service staff must be well trained; among them will be found engineers and Ph.D.'s in abundance. A hearty manner and a pocket full of cigars are no longer the maximal entrance requirement for this field. The average sales representative is well informed and can make useful suggestions and recommendations. The training of these people is largely the burden of the manufacturer; in many concerns, actual instruction for an extended period has been found necessary.

Every large manufacturer carries some "prestige" items—instruments on which he definitely loses money. Some of these are carried as a matter of pride, others with the feeling that he can turn back to pure science something which it needs but for which there is not sufficient demand to warrant profitable manufacture. The large selling items of a standard nature are counted on to balance the losses. Despite this, he is often told that an instrument is satisfactory but its price is outrageous.

Dealers

The role of the apparatus and instrument dealer is very important. He is frequently misunderstood but just as frequently cherished by those who appreciate his function. The dealer is in a position to place his wide experience and contacts at the disposal of the general customer. He is required, by the nature of his business, to carry a stock of 20,000 to 30,000 items. A single rush order may consist of one Type X potentiometer and 50 grams of calomel, and Heaven help him if he hasn't both on hand for immediate delivery.

The average dealer is a clearinghouse for scientific information. He is frequently called upon to offer advice about the choice of equipment, comparative prices, or the feasibility of a certain process or method. He is often requested to furnish complete laboratories or assemblies of equipment. Routine inquiries at the rate of dozens a day may range from the way to remove a frozen stopper or to demonstrate cold light, to how to check the ABC pH meter (not his own listing). These questions are answered cheerfully and patiently; they are part of his service. As a general rule, this service is not unappreciated. There are countless executives, educators, and technical people who have relied upon their favorite dealer for decades and express their gratitude by continued patronage.

Many dealers engage in development and research work to improve their offerings and to reduce their cost. They often undertake the construction of special apparatus and assist the customer in the solution of his problems.

Consumers

The purchaser of apparatus has his own problems and a few pet peeves.

In general, the large-scale user of industrial instruments knows just what he wants, his demands are somewhat more standardized, and cost is not a primary consideration. Furthermore, he understands costs because he is in business himself.

The individual and the academic consumer will incline to home-made apparatus, often of necessity. Despite generous academic discounts, he may be required to buy apparatus on a basis of price rather than on performance or specification. Frequently he has need for an instrument of limited applicability, too intricate for an amateur to build, and too unprofitable for a dealer or manufacturer to undertake.

He is confused or annoyed, as the case may be, by rival claims of superiority in instruments. He is aware that many advertising claims are not supported by the facts. He notes that in such claims precision and accuracy are confused, sometimes intentionally. It should be noted that conservative companies are more indignant about these occurrences than is the consumer.

He is aware that all companies are not equally progressive, and that mere size of the company is no reliable index in this respect.

Scientific Apparatus Makers of America

To this organization, of which nearly all manufacturers and dealers are members, science and industry in this country are greatly indebted. It has done effective work in standardization, in seeking uniformity and cooperation among various agencies, and in studying impending legislation which might be harmful to the best interests of independent American industry. It was instrumental in founding the *Review of Scientific Instruments* and maintained that valuable journal until it was absorbed by the American Institute of Physics. Once more (1940) it has collaborated with the management and materially contributed to its support. But for the untiring efforts of this organization, especially in the post-war period, the American instrument and apparatus industry would not occupy its present commanding status.

American Instruments and Apparatus

The author has confined this review exclusively to American made equipment, with a single exception (Figure 109). In the broadest scientific sense, this is unsatisfactory; but it may be contended that an inquiry conducted on this basis is timely and pertinent. In many respects we have a complete degree of independence; in the electrical and control field it is the general consensus of opinion that American practice is 10 or 15 years ahead of other countries. Some doubt is expressed about the optical field, but at least what has been accomplished is impressive.

This brief sketch may convince those who are devoted to the advancement of science, progress in technology, and the maintenance of our public health and defense that there is an imposing array of talent—physicists, chemists, and engineers—producing new and better equipment, to bring ever-increasing precision and certainty to bear upon these problems.

National Bureau of Standards

American science and industry are heavily and continuously indebted to the National Bureau of Standards, particularly in the case of instruments and apparatus. This institution is housed in twelve major and seven minor buildings on 56 acres of land in the northwest suburbs of Washington. In 1939, 950 employees (*42*) staffed nine divisions devoted to research and testing (70 sections), three divisions dealing with commercial standardization (14 sections), and three divisions for administration, operation of plant, and the construction of apparatus (19 sections). In a typical report for one year's activities (*32*) and considering only those items referring to instruments we find that there were tested:

1,440 electrical standards and instruments
3,190 gages and samples of gage steel
5,110 weights and balances
420 timepieces
13,700 pieces of volumetric apparatus
1,820 hydrometers
2,360 laboratory thermometers
141,600 clinical thermometers
1,630 engineering instruments
1,035 aeronautic instruments

During the same period the bureau distributed 8620 standard samples and analyzed 87,640 other samples. In the past year approximately 10,300 standard samples were sold to industrial, municipal, state, government, hospital, and university laboratories (*21*). There are few, if any, readers of the ANALYTICAL EDITION who are not familiar with and grateful for this service.

This does not take into account a large amount of research, much of it fundamental, which in its long-range effects is always difficult to appraise in an annual report. Such research has been actively prosecuted during most of the 40 years since the bureau was established. In addition to the maintenance of fundamental standards suitable for all scientific and industrial pursuits and continued research on improved methods of defining and applying them, the bureau maintains close contact with foreign bodies and commissions dedicated to the same duties.

Its services are available to the national and state governments without charge. Other work is undertaken under certain conditions, the main consideration being the value of the work to the nation as a whole. For private tests a fee is charged, which is turned into the U. S. Treasury and is not available to the bureau. Even the casual reader cannot fail to be impressed by the enormous output of this institution for the small cost which it entails. For 1939 the appropriation was only $2,615,000.

The results of the past year's work have been made available through 288 publications and articles. In addition, 30 mimeographed letter circulars and notes on subjects concerning which many inquiries were received, were prepared and distributed on request.

Secondary Standards Maintained by Manufacturers

It is common knowledge that most instrument and apparatus manufacturers will submit their wares to the National Bureau of Standards for certification at the request of the customer. The majority maintain their own secondary standards which are sent to the bureau for periodic checking. In many cases the private resources for such standardization and calibration are in no wise inferior to those of the bureau, although the official nature of the bureau's approval is universally accepted, and in view of its general policy, the ultimate consumer has reasonable certainty that his results will conform with international usage.

Courtesy, Ford Motor Co.

FIGURE 2. MASTER SET OF GAGE BLOCKS

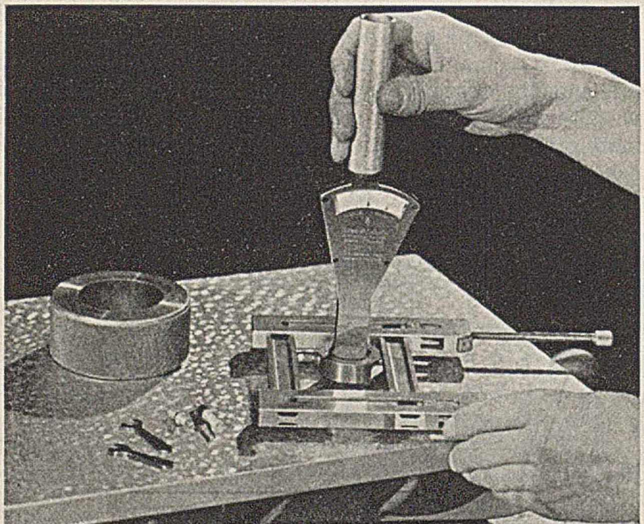
It is, perhaps, less generally appreciated that the present-day methods of fabrication permit the manufacturer to turn out equipment which he knows, in advance, will be suitable for official certification. In the past it was customary to sort or grade production items and select the best specimens for this purpose. With constant improvement in production methods, the increased use of automatic machinery, and the extensive application of instrumentation, this practice is becoming less and less common.

Length and Linear Displacement

In linear and angular measurements the present demands for exceedingly close tolerances in many of our machines, particularly in the automotive industry, have necessitated the production of comparatively cheap high-precision standards of length. The first combination set of gage blocks was made by C. E. Johansson of Eskilstuna, Sweden, in 1897, but it was not until 1911 that he was able to produce them in commercial quantities of a guaranteed quality.

Johansson gage blocks are rectangular pieces of hardened steel with finished flat surfaces having the appearance of burnished silver and are accurate within millionths of an inch. Their production requires the attainment of perfectly flat surfaces, strict parallelism of the faces, accuracy of dimensions, and appropriate heat treatment and seasoning to assure permanence. When "wrung" together the blocks will adhere with a force which is about thirty times greater than can be accounted for by the atmospheric pressure component. A large stack of them may be held as shown in Figure 1, and the total length is equal to the sum of the individual unit lengths within a few millionths of an inch. When the Ford Motor Company acquired the right to manufacture these gages, the accuracy was of the order of 0.00001 inch. In successive stages of improvement and development, this accuracy was increased to 0.000008, 0.000004, 0.000002 inch. A typical standard set, shown in Figure 2, consists of 81 blocks, from which 120,000 combinations of gages can be made in steps of 0.0001 inch, from a minimum size of 0.200 inch to more than 12 inches. Series are available in English or metric units. The Johansson gage blocks are made in B, A, and AA quality having an accuracy at 68° F. of per block up to 1 inch of length and per inch of length on longer blocks. In the AA quality the flatness, parallelism, and dimensions are held to within an eighth of a wave length of light!

Quality	*Inch*	*Mm.*
B	±0.000008	0.0002
A	±0.000004	0.0001
AA	±0.000002	0.00005

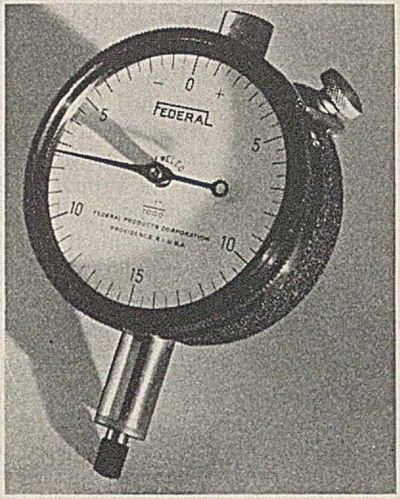


Courtesy, Ford Motor Co.

Figure 3. Setting Master Visual Gage with Blocks

One of the many uses of these convenient standards is shown in Figure 3, in which a master visual gage is being set. The same procedure can be used in checking micrometers, go, no-go snap gages, and dial and limit gages.

The National Bureau of Standards, which is the repository for the platinum-iridium National Standard Meter No. 27, has prepared standards of length from fused quartz known to 1 part in 5,000,000 and three standards for planeness for testing gages, flat to within 0.0000002 inch.



Courtesy, Federal Products Corp.

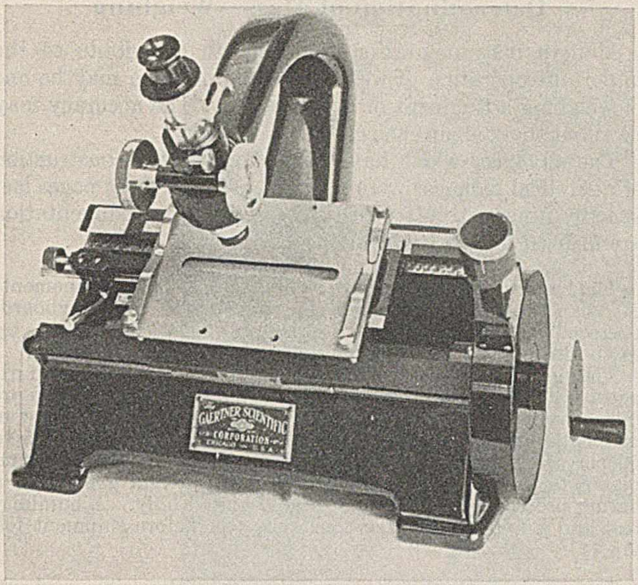
Figure 4. Dial Gage

Dial Gages. Small changes or variations in linear dimensions or small displacements are conveniently measured with dial gages similar to the one shown in Figure 4. This instrument reads increases or decreases in length in thousandths of an inch up to 15 thousandths. These gages are available in five sizes graduated from 0.00025 to 0.005 inch. In addition to their individual use these instruments are often used as important components of other testing instruments and machines. Any phenomenon which can be conveniently converted into linear motion, such as thermal expansion, deflection under stress, etc., can be transmitted directly to the gage. Although these gages are held to very close tolerances, it is always possible to check them in terms of fundamental standards such as the afore-mentioned Johansson gage blocks.

The Comparator is a versatile and useful instrument, as likely to be found in the toolroom of a factory as in the computing room of an astronomical observatory. Comparators are favorite topics for discussion in treatises on machine or instrument design, since a good one embodies so many principles that are fundamental in correct design theory.

The instrument illustrated in Figure 5 was designed primarily for the measurement of spectrograms, but may be used for linear measurements on any objects within the capacity of the stage.

The instrument has a range of 100 mm. and is direct-reading to 0.001 mm. The large-diameter lead screw has a pitch of 1 mm. Periodic and progressive errors are eliminated and the bearings are free of eccentricity. The "traveling-nut" of bronze is split to allow compensatory adjustment for wear. An arm on the nut rides on a "correction bar" which provides such small rotation as is necessary to correct the slight residual errors in the screw. The nut moves the carriage through the medium of a ball and flat contact. Weight loading maintains the carriage in uniform contact with the nut.



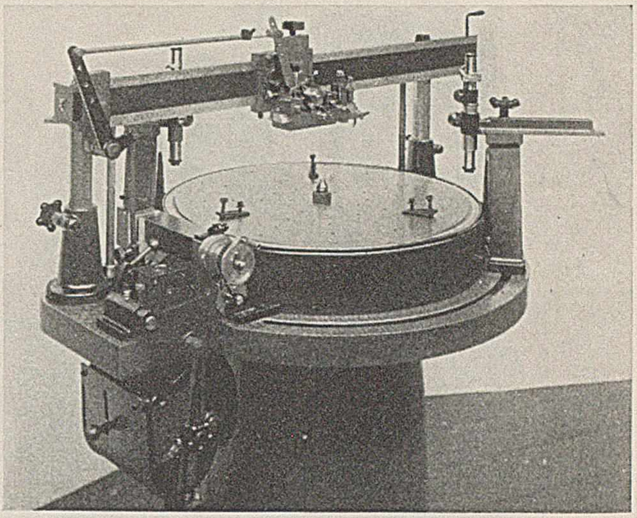
Courtesy, Gaertner Scientific Corp.

FIGURE 5. COMPARATOR

A continuously variable range of magnification from 5 to 35 diameters is provided by the microscope through a choice of objectives of 32 and 35 mm. and two eyepieces of 25- and 50-mm. equivalent focal length. The micrometer drum is 135 mm. in diameter with 1000 divisions each representing 0.001 mm. A second drum, adjacent to and coaxial with the first, indicates the number of complete revolutions, thus supplementing the millimeter scale mounted on the bed. The entire reading is apparent at a glance; thus 61.468 mm. is given by 61 complete revolutions and a reading on the immediately adjacent drum of 468. The scales are viewed by a magnifier through a glass window, with uniform illumination provided by a diffusing screen. Relative measurements are consistent with one another to well within 1 micron over the full range, and the total length is accurate to 1 micron at 22.5° C.

DIVIDING MACHINE. One is inclined to regard a dividing machine as a precise tool and not as an instrument, yet it possesses all the refinements of a precise instrument and is indispensable in the manufacture of many of them. Dividing machines are of the linear or circular type, and of wide variety of range and accuracy. They may be manually operated or completely automatic.

The machine illustrated in Figure 6 is completely automatic and will rule circular scales up to 62 cm. in diameter on flat, curved, beveled, or vertical surfaces with an accuracy of ±1 second of arc. A wide choice of angular spacings is available in degrees, minutes, and fractions thereof, or fractions of a circle, and in rulings suitable for the special requirements of artillery. To attain this precision requires the use of seasoned, strain-free materials, a worm wheel with all teeth ground and lapped, and a fully corrected worm screw. Residual errors in the worm wheel are corrected by automatically shifting the worm screw along its axis. A lever and cam system accomplishes this. The entire table, and work mounted on it, rotate on a long conical axis of hardened steel. An adjustable helical spring takes up the weight, assuring constant minimal friction and uniform accuracy.

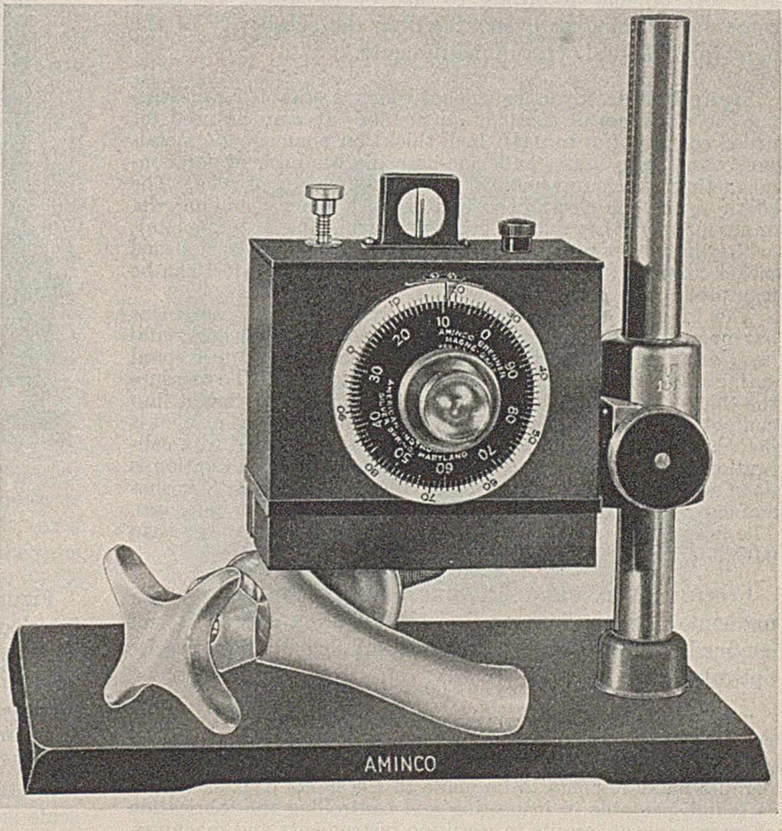


Courtesy, Gaertner Scientific Corp.

FIGURE 6. CIRCULAR DIVIDING MACHINE

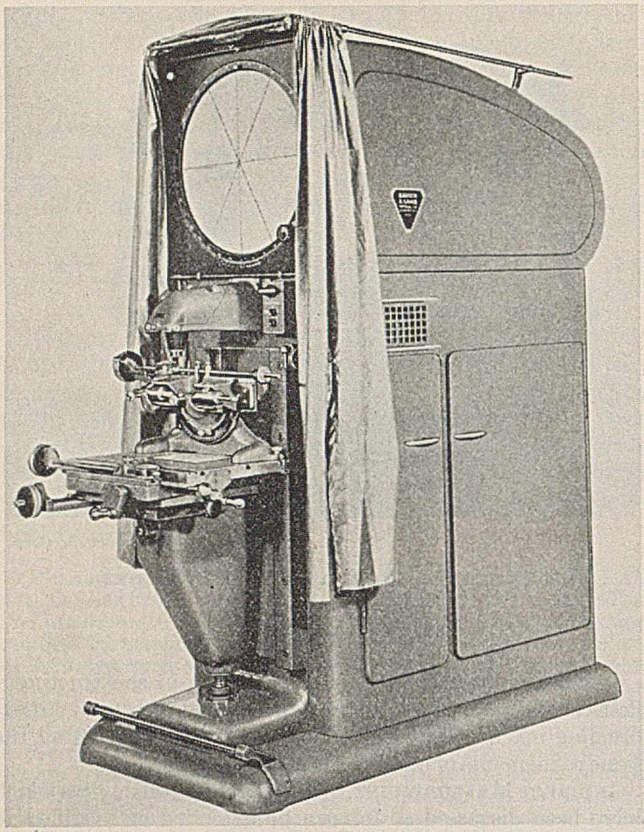
A machine of this type is indispensable in constructing a first-class goniometer, spectrometer, or polarimeter. Linear dividing machines are still more widely used and entail the same refinements of construction.

INDIRECT MEASUREMENT. The fundamental devices which have been discussed so far can be extended or modified to meet special requirements. On the other hand, indirect methods have been used for the measurement of length, thickness, or lineal displacement. Electronic and photoelectric installations are commonly used to inspect, grade,



Courtesy, American Instrument Co.

FIGURE 7. MAGNA-GAGE



Courtesy, Bausch & Lomb Optical Co.

FIGURE 8. CONTOUR-MEASURING PROJECTOR

and sort objects according to size or thickness, in many cases approaching or even exceeding the sensitivity of the more fundamental types of instruments.

Figure 7 illustrates an instrument which is suitable for measuring the thickness of coatings on metals. It may be used for nickel coatings (up to 0.001 inch thick) on nonmagnetic metals such as copper, brass, and zinc-base die castings, or for nonmagnetic coatings (up to 0.025 inch thick) on iron or steel. The coatings may be electrodeposited (copper, zinc, cadmium, tin, or chromium); they may be hot-dipped (tin, zinc, or terneplate); or they may be nonmetallic (paint or vitreous enamel). Polished nickel coatings (up to 0.002 inch thick) on iron or steel can be measured.

The Magna-Gage consists essentially of a small permanent bar magnet, 2 mm. in diameter, freely suspended from a horizontal lever arm. The latter is actuated by a beryllium-copper spiral spring which is coiled by turning a graduated dial. To measure the thickness of a coating, the tip of the magnet is brought into contact with the specimen and the dial turned until the magnet is detached. The average of several readings is referred to a calibration curve relating dial readings to thickness. Calibration is done at the National Bureau of Standards, which also furnishes standard coatings with the calibration for checking purposes. The accuracy is about ±10 per cent for coatings thicker than 0.0002 inch.

CONTOUR-MEASURING PROJECTOR. The accurate measurement of dimensions and dimensional variations is not confined to mechanical means but is supplemented by precise optical projectors.

The Bausch & Lomb contour-measuring projector shown in Figure 8 provides a means of producing a greatly enlarged image of comparatively large objects on a ground-glass screen and permits measurements to be made to the limits of 0.0001 inch. It is indispensable in inspecting and controlling the fabrication of interchangeable units in precision instruments and machines. In attaining this degree of precision the very best optical components must be employed.

Determination of Mass—Weighing

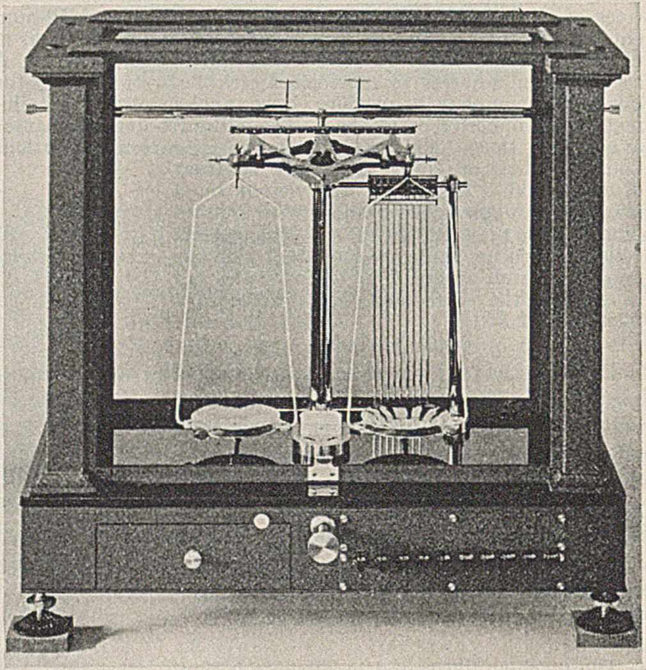
Modern instrumentation continues to contribute to the important operation of weighing. The problem may be one of weighing a fragment or a freight car. The accuracy may be about the same in each case.

The advances which have been made in the construction of analytical balances were ably discussed in these pages last year by Ainsworth (*1*); the full resources of instrumentation are utilized in this problem.

The balance shown in Figure 9 embodies the latest refinements of balance construction, with the convenience of a keyboard-operated weight carrier, which handles all fractional weights up to and including 1 gram, having a total capacity of 2220 mg.

The preparation of high-precision (Class M) weights is an expensive and tedious process. The one-piece bronze weights are first heavily gold-plated and then given a 3-hour boiling test in distilled water. This is to detect porosity and results in 25 to 50 per cent rejects. The weights passing this test are rhodium-plated to bring them up to standard weight and give them a harder protective coating than if gold-plated only. A humidity test and a final 90-day age constancy test before shipment follow (*1*).

INDUSTRIAL BALANCES AND SCALES. Precision and refinements in weighing are not confined to the research laboratory. In many respects there have been more innovations and developments in the industrial field. As usual, the fundamental requirements are speed and reliability consistent with accuracy.

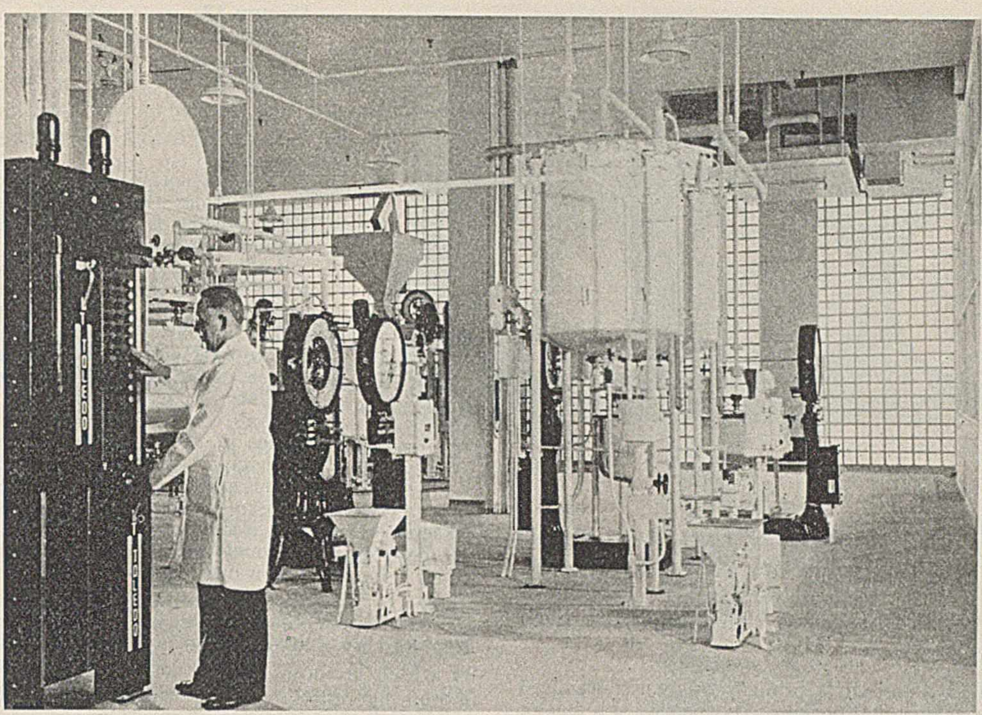


Courtesy, Wm. Ainsworth & Sons, Inc.

FIGURE 9. PRECISION ANALYTICAL BALANCE

Figure 10 illustrates a battery of Toledo scales electrically interlocked and controlled through the panel at the left. They are used in the accurate proportioning of several ingredients used in the preparation of a cosmetic and are equipped with photoelectric cutoffs.

Balances and scales are frequently used as components of other instruments or machines and indirectly furnish information other than weight. For example (Figure 11), a scale is used in an electrically operated machine which automatically checks valve springs for compressive strength, and classifies them. The springs are discharged through one of



Courtesy, Toledo Scale Co.

FIGURE 10. AUTOMATIC ELECTRIC SCALES FOR PROCESS CONTROL

the spouts at the right, depending on whether they are accepted or rejected.

Time Measurements

The measurement of time or frequency is a common operation in scientific work. For measurements of moderate precision, an electric clock driven from the alternating current mains has supplanted most other forms of timepiece. For reasons which are peculiar to central station operation, and for the exchange of power by neighboring power networks, the policy of maintaining constant frequency by the power companies will continue to be expanded and eventually become a generally available service.

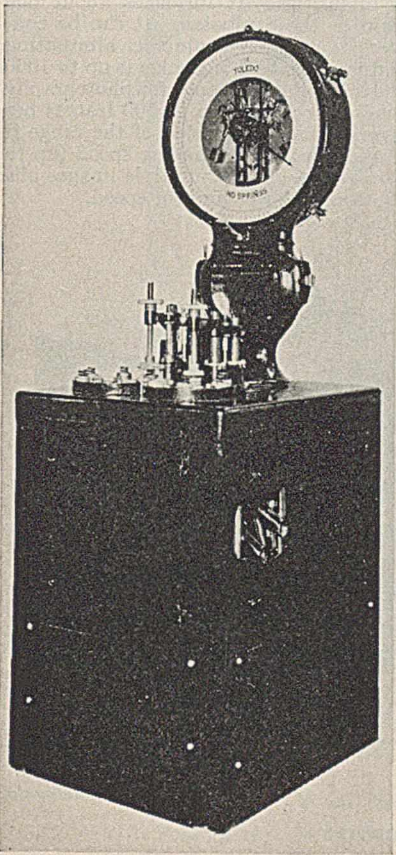
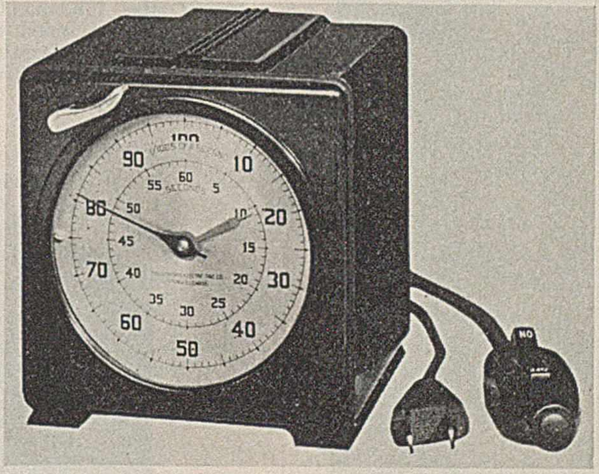


FIGURE 11. SCALE-CONTROLLED SORTING MACHINE

Courtesy, Toledo Scale Co.

Precision electric timers of this class are available in a variety of styles and ranges. The one shown in Figure 12 is rated at 1 r. p. s. and totalizes 60 seconds. It can be provided with a clutch operating from 110-volt alternating current, any direct current voltage from 6 to 110, or from the output of electron tubes. The accuracy with the former is 0.01 second and with the latter 0.005 second. Control may be either automatic or manual. For particular applications a variety of combinations are possible, as, for example, the chrono-tachometer of Figure 13 in which engine or motor speeds may be timed by integrating revolutions and time. The timer and counter may be started and stopped simultaneously by unit control and a tachometer is provided to show the approximate instantaneous speed.



Courtesy, Standard Electric Time Co.

FIGURE 12. PRECISION ELECTRIC TIMER

Fundamental time measurements are based on astronomical observations. In this country the U. S. Naval Observatory transmits high-precision time signals through the Naval Radio Station at Arlington, Va., on a frequency of 113 kilocycles, 21 out of the 24 hours. An electronic oscillator of constant

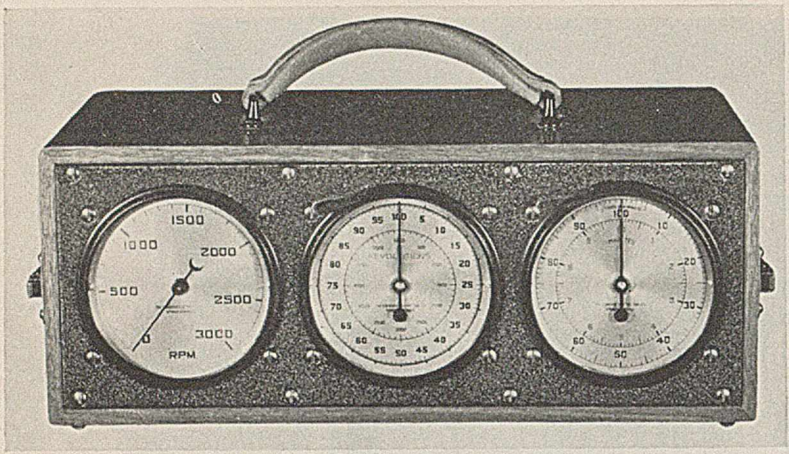


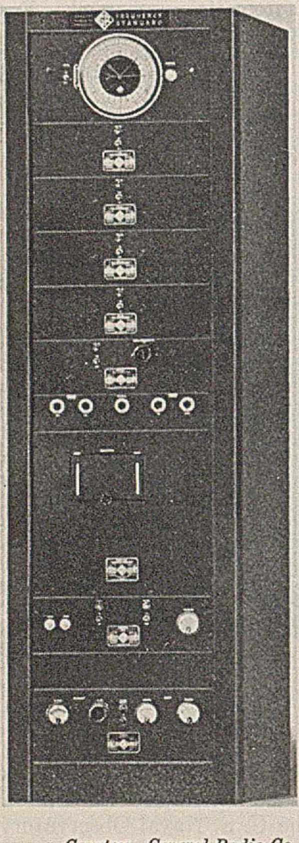
FIGURE 13. CHRONO-TACHOMETER

Courtesy, Standard Electric Time Co.

frequency may be compared periodically with these signals and under suitable circumstances one may therefore have either a primary frequency standard, checked in terms of time, or a timepiece the reliability of which may be checked at frequent intervals.

The General Radio Company's primary frequency standard (Figure 14) can serve this dual purpose. It consists of a master 50-kilocycle oscillator with means for multiplying or subdividing this frequency and in the latter case for obtaining an output of suitably low frequency to drive a synchronous motor (clock). As a source of electrical oscillations, frequencies from one pulse a second to several megacycles can be obtained from this equipment.

The instrument consists of a power supply operating from the ordinary alternating current mains, 115 or 230 volts, 50 to 60 cycles; and the master oscillator, the frequency of which is controlled by a quartz bar ground and adjusted to within 1 part in 10,000,000 of its specified frequency in terms of standard time. This crystal is also thermostated to within 0.01° C., reducing ambient temperature errors to no more than 0.2 part in 10,000,000. Multiplication or subdivision of the fundamental frequency is obtained by several stages of relaxation oscillators called multivibrators. They are characterized by an abundance of harmonics (several hundred) and susceptibility to control by an introduced voltage whose frequency lies near their fundamental on a low-order harmonic frequency. In performing this function they act as slave-oscillators, maintaining the same precision as the master oscillator.



Courtesy, General Radio Co.

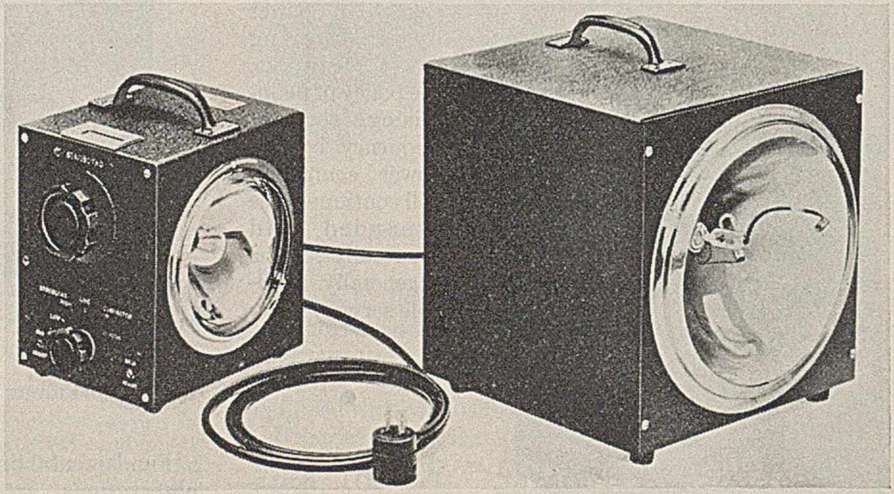
FIGURE 14. PRIMARY FREQUENCY STANDARD

The synchronometer shown in the center of the top panel effectively counts the number of cycles executed by the standard piezoelectric oscillator in a standard time interval. A microdial contactor, operating once each 50,000 cycles of the standard oscillator, is provided for comparison with time signals. The accuracy of this and all other frequencies is better than ±5 parts in 10,000,000 over periods of several months. In terms of time this is less than 1 second per month! Since time comparisons can be made several times daily, the frequency (or time) is known with a high degree of precision at all times.

Closely related to time measurements are the services rendered by a stroboscope, a convenient and versatile form of which is shown at the left of Figure 15. With its aid, a moving object may be viewed intermittently, thus producing the optical effect of slowing down or arresting the motion.

The Strobotac is a portable stroboscope calibrated to read speed directly in revolutions per minute. The light source is a special neon lamp mounted in a parabolic reflector. It is driven by a relaxation oscillator and the flashing speed can be varied by a direct-reading dial to any value between 600 and 14,400 r. p. m. Provision is also made for control by an external contactor or by the alternating current line frequency. The instrument can be standardized at any time from a frequency-controlled power line by means of the vibrating reed, which can be seen in the lower part of the reflector.

The unit shown on the right in Figure 15 provides a power supply and lamp for higher intensities. It furnishes about one hundred times as much light as the Strobotac. It can be controlled by the latter or by an external contactor, alternating current line, or other oscillator. The flashing range is up to 1000 per second. It is well suited among other things for photography with a continuous-film camera for speeds up to 100 frames per second. With both units considerable extension of the range is possible by making use of multiples of the flashing speed (up to 100,000 r. p. m. for the Strobotac), and by multiple images one can go somewhat below the normal lower limit of speed.



Courtesy, General Radio Co.

FIGURE 15. STROBOTAC

Temperature Production, Measurement, and Control

The few examples which are included here are concerned primarily with laboratory applications and not with industrial temperature recorders and controllers.

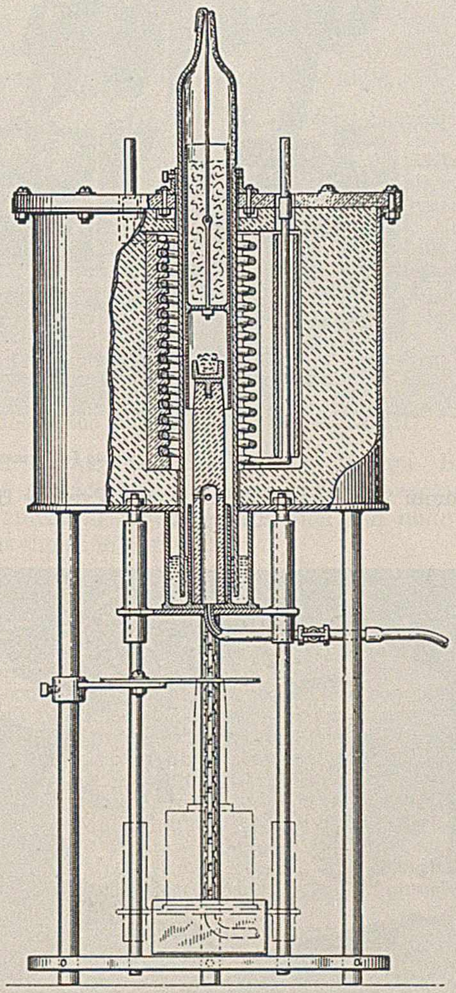
A NEW COMBUSTION FURNACE. A vertical-type combustion furnace, designed primarily for the determination of carbon in iron and steel, is shown in Figures 16 and 17. Chief among the advantages are the small bench space required and the use of mechanical loading.

The sectional diagram shows the constructional details. A vertically moving plunger supports the sample, directly centered, in the heating zone, and also makes a gas-tight seal at the lower end of the combustion tube. When the plunger is lowered, the receiving end for the crucible is on a level with a swinging loading shelf which holds the next sample. While one determination is being finished (weighing the carbon dioxide absorption tube) the next sample is being preheated, awaiting the admission of oxygen.

The furnace has the customary steel shell enclosure with suitable insulation surrounding a helical coil of alloy No. 10, capable of being operated continuously at 2300° F., though 2050° F. has been found satisfactory.

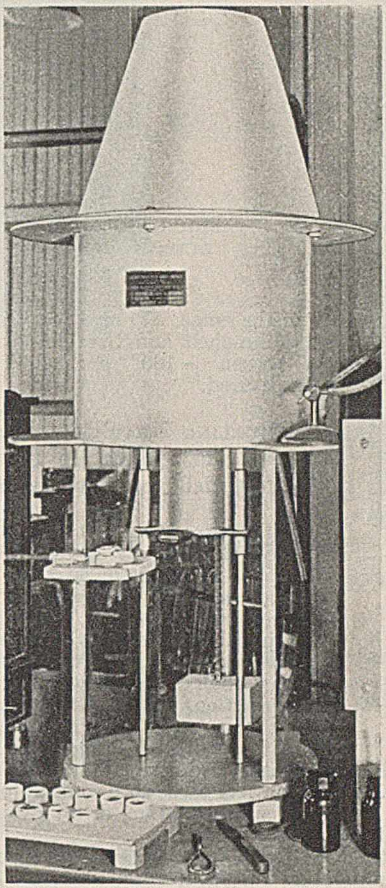
The relative speed of operation for 1-gram samples is said to be 3 minutes under conditions requiring 10 minutes for the old style of furnace.

TEMPERATURE MEASUREMENTS. The International temperature scale is defined in terms of the platinum resistance thermometer in the range of −190° to 660° C. Practically every manufacturer of temperature-measuring devices of all classes uses or has access to a platinum resistance thermometer and the necessary electrical instruments. On this basis, secondary standards can be maintained for all classes of thermometric devices. Resistance thermometers in general are widely used, the platinum type as standards of high accuracy and nickel elements for somewhat higher sensitivity and use in industrial recorders and controllers.



Courtesy, Hevi Duty Electric Co.

FIGURE 16. COMBUSTION FURNACE



Courtesy, Hevi Duty Electric Co.

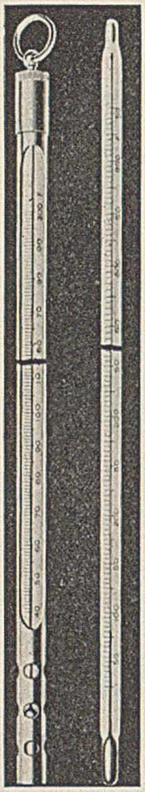
FIGURE 17. FURNACE USED IN CARBON DETERMINATIONS

Glass thermometers are made in great variety and for many special purposes. The search for improvement continues unabated—for greater precision, stability, and ease of reading.

Figure 18 illustrates typical modern thermometers of borosilicate glass of the total-immersion type, one fitted with nickel-plated steel armor. Details which are not immediately apparent but are reflected in performance of a good thermometer are the use of uniform flat-bore tubing (oval cross section), improved expansion chambers, deep etching of graduations and the use of durable pigments therein, and pressure filling with an inert gas.

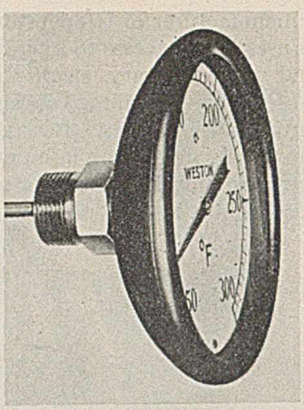
DIAL THERMOMETERS. Bimetallic, dial temperature gages for general laboratory and industrial use are finding increased applications.

The gage shown in Figure 19 is of the heavy-duty type with a stainless steel connection nut for standard 0.5-inch pipe. The scale has a length of 9 inches on a 5-inch diameter head. For correct indications a stem immersion of at least 2 inches is required in liquids and 4 inches in gases. The accuracy is within 1 per cent of the range over the entire scale. Another series, designated as testing thermometers, is accurate to 0.5 per cent



Courtesy, C. J. Tagliabue Mfg. Co.

FIGURE 18. BOROSILICATE GLASS TOTAL-IMMERSION THERMOMETERS



Courtesy, Weston Electrical Instrument Corp.

FIGURE 19. DIAL THERMOMETER, HEAVY-DUTY TYPE

of the range. From a wide choice of ranges (Fahrenheit and Centigrade) temperatures between −100° and 400° C. can be measured.

BURLING HEAT CONTROLS. These instruments operate on the principle of differential expansion of solids, Figure 20.

The expanding element is carried in an alloy tube rigidly fastened to the head. Motion is communicated to a rocker arm mounted on ample bearings with stainless steel bearing pins. The free end carries adjustable pins that operate the microswitches, which are characterized by the very small displacement necessary for positive action. The model shown here is fitted with two switches, which make it possible to (1) control heating or cooling or both, (2) control the temperature and give either a high or low limit device, (3) give either two- or three-step control, (4) give floating control with reversing control motors, or (5) give two- or three-speed control of auxiliary motors.

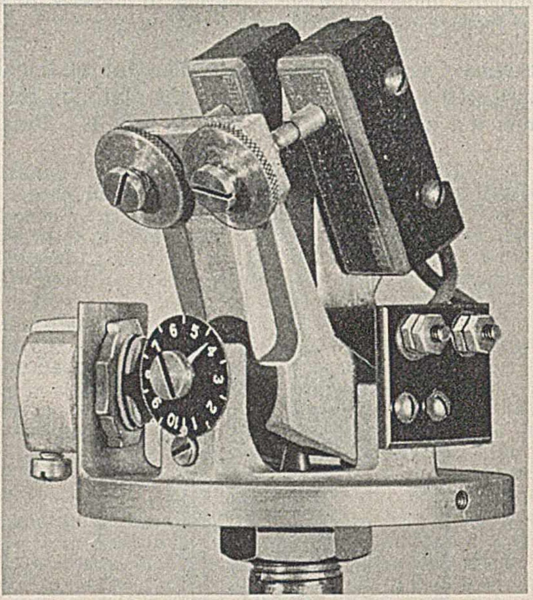
These controls are available in tubes of any specified metal or alloy, for temperature ranges from −100° to 1400° F., with special tubes up to 1600° or 1800° F. The operating differentials vary inversely as the length of the tube exposed to changing temperatures, varying from ±0.25° to ±25° F. The switches have the usual rating for this class: of the order of 1250 watts' noninductive load.

These controls have a high degree of reliability, accuracy, and simplicity.

(For descriptions of precision thermoregulators, see page 629.)

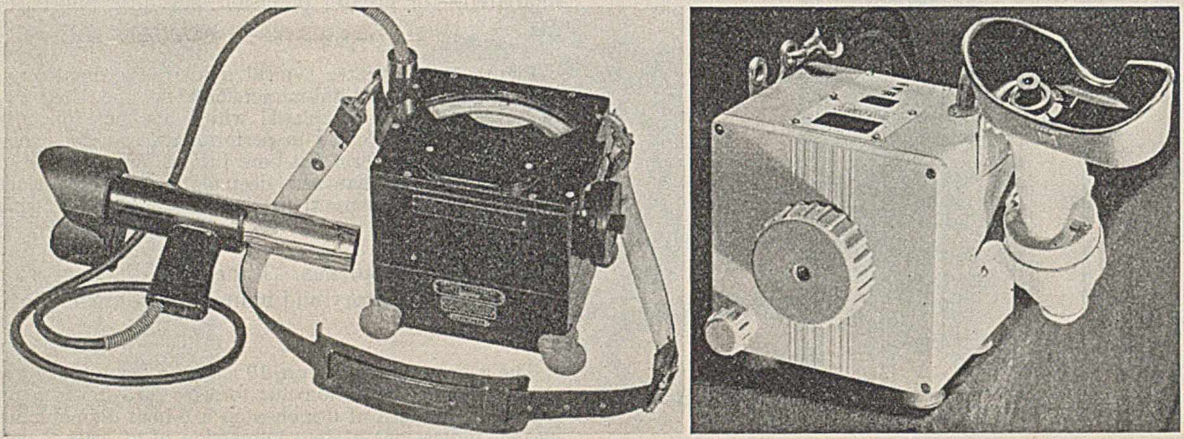
LEEDS & NORTHRUP OPTICAL PYROMETER. For many years the disappearing-filament type of optical pyrometer has been used, in which the image of a small lamp filament is matched against the field produced by the incandescent object which is being measured. A milliammeter measures the lamp current, and from suitable calibration data the temperature may be determined. The chief difficulty has been with the meter, which often became fouled by magnetic impurities, dust, etc., drawn into the case by abrupt temperature changes when the instrument was carried from a hot to a cool location.

In Figure 21 is shown a new and improved optical pyrometer which replaces its well-known predecessor on the left. The two illustrate the radical advances in the design of instruments. More important differences are to be found inside the instrument. A potentiometric system is employed instead of the lamp current measuring milliammeter. The



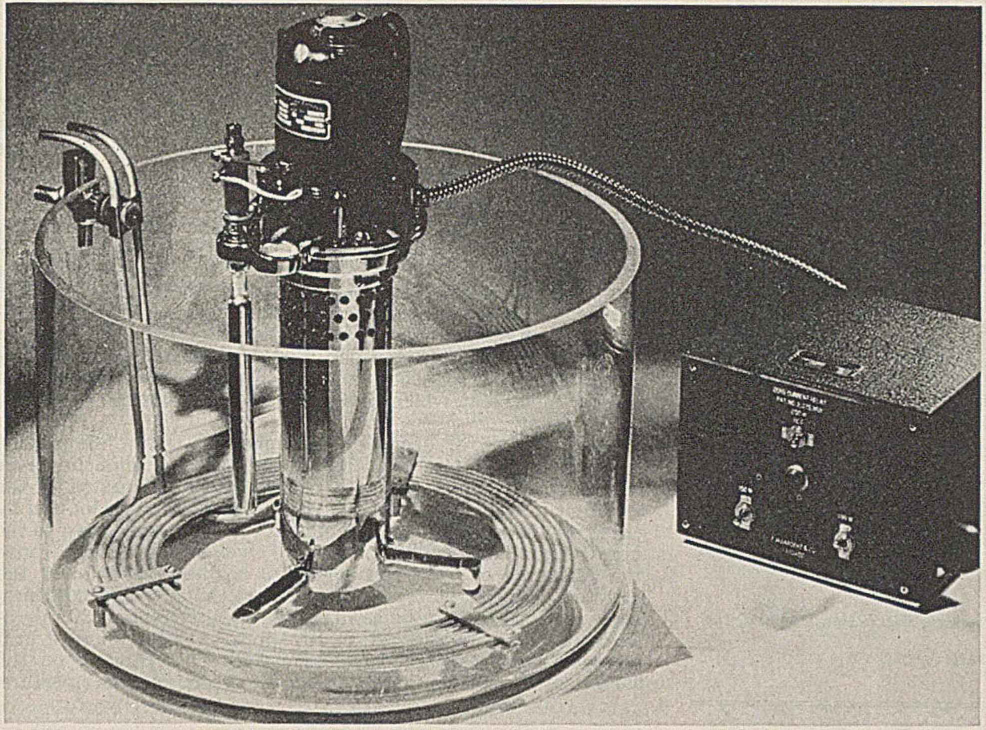
Courtesy, Burling Instrument Co.

FIGURE 20. THERMAL EXPANSION TYPE OF HEAT CONTROL



Courtesy, Leeds & Northrup Co.

FIGURE 21. OPTICAL PYROMETER (Left, Previous Model; Right, Potentiometer Type, Latest Model)



Courtesy, E. H. Sargent & Co.

FIGURE 22. CONSTANT-TEMPERATURE WATER BATH

circuit has been described by Machler (*24*) and his paper should be consulted for more complete details.

To avoid excessive drain on the standard cell, an ingenious follow-up mechanism is coupled to the shaft of the slide wire which adjusts the lamp current, maintaining the potentiometer in approximate balance at all times. The final balance adjustment does not disturb the lamp current. The galvanometer is doubly protected against magnetic dust by its own closed container and the general filter arrangement of the whole case. In any case, dust could not affect the calibration of the pyrometer; it could only impair the sensitivity of setting. The instrument can quickly be adapted to measure temperatures of objects down to 0.01 inch in diameter and smaller.

The new pyrometer is faster and easier to operate and requires no calibration chart, and despite all the new improvements weighs a third less than the earlier instrument. Complete details may be found in the manufacturer's Catalog N-33D.

SARGENT CONSTANT-TEMPERATURE WATER BATH. A thermostat providing a large unobstructed working area, with guaranteed accuracy of regulation and uniformity of 0.01° C., is shown in Figure 22.

The compact central tower contains heating units and an efficient screw impeller for circulation. The heat transfer is fast and efficient. The unit occupies only 20 per cent of the total surface area. A mercury regulator is fastened to this unit and a socket is provided for introducing a Beckman thermometer. A removable cooling coil is provided, as well as a constant-level device. A heavy flexible cable connects with the electronic control cabinet, which is provided with main switch, switch for an auxiliary heater, and pilot lamp. The container is a transparent, heavy molded Pyrex jar with 0.25-inch wall, drilled for the constant-level device, and with the top rim ground. A protective dust cover of heavy aluminum in two halves may be obtained.

This very efficient unit is well designed, compact, and provides a large amount of free working space. The clear transparent walls are a distinct advantage for many types of observation.

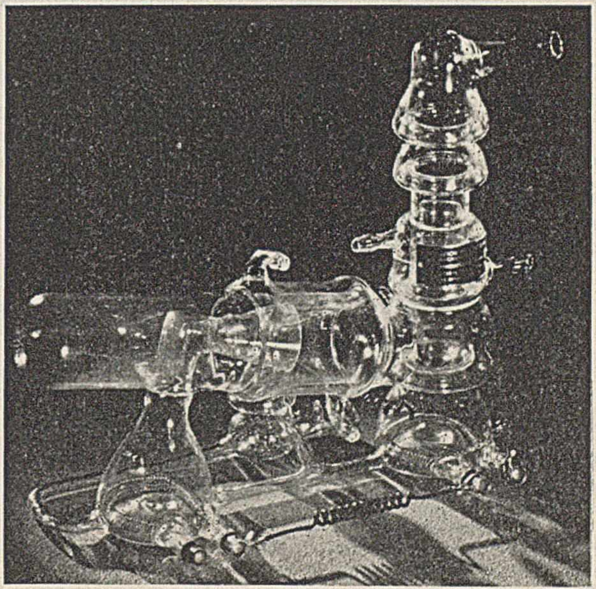
High Vacuum and Measurement and Control of Gases

Modern research continues to make increasing demands on high-vacuum technique. Many industries require the production, and measurement or control of high vacua—i. e., incandescent lamps, x-ray tubes, electron tubes, and more recently molecular distillation on a semiplant scale.

Figure 23 illustrates one of a series of efficient pumps which have been developed for the exacting requirements of modern practice. It is an all-glass, 3-compartment, 2-jet diffusion pump. Using Octoil-S as a pump oil it will produce a pressure of 5×10^{-7} mm. with air cooling and without a cold trap. A backing pressure of only 0.20 mm. is required and at 10^{-4} mm. pressure the pumping speed is 12 liters per second. The heaters are operated in series with a rheostat from a 110-volt line. Various models are available with pumping speeds ranging from 3 to 220 liters per second, producing pressures from 10^{-5} to 5×10^{-8} mm. In most cases still lower pressures may be attained if a cooled trap is employed. An exclusive feature is the design which effects continuous purification of the pump oil during operation, thus maintaining the high vacuum and pumping speed and continuously rejecting impurities.

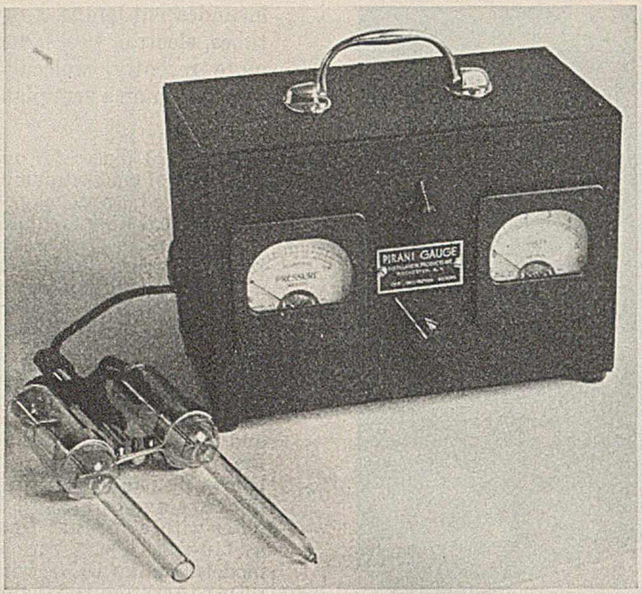
Metal pumps embodying the same features, but using cooling water, are available as high-speed fractionating units and are particularly suited to the exhaustion of large systems such as cyclotrons, vacuum spectrographs, vacuum furnaces, and radio transmitting tubes. Again, no cold trap is required. They can be designed for pumping speeds as high as 1000 liters per second.

For use in these pumps, several new organic fluids of very low vapor pressure have been synthesized, which are more



Courtesy, Distillation Products, Inc.

FIGURE 23. ALL-GLASS DIFFUSION PUMP



Courtesy, Distillation Products, Inc.

FIGURE 24. PIRANI GAGE

TABLE I. ULTIMATE VACUUM OF PUMP FLUIDS

Name	B. P. at 10^{-2} Mm. ° C.	Ultimate Vacuum Mm.
Amoil (*n*-amyl phthalate)	100.0	2.5×10^{-5}
Amoil-S (*n*-amyl sebacate)	111.0	3.1×10^{-6}
Octoil (2-ethyl hexyl phthalate)	122.5	2.5×10^{-7}
Octoil-S (2-ethyl hexyl sebacate)	143.5	5×10^{-8}
Butyl phthalate (special)	85.0	10^{-4}

stable than compounds previously available. The values given in Table I indicate the ultimate vacuum as measured with an ionization manometer at 25° C. using a 4-compartment, 3-jet pump without a cooling trap.

MEASUREMENT OF HIGH VACUA. The well-known monographs on the production and measurement of high vacua by Goetz, Dushman, Kaye, and Dunoyer all give complete discussions of the technique of these operations. Distillation Products, Inc., has supplemented its valuable series of pumps by very convenient rugged units for the rapid measurement of low pressures.

The Pirani gage shown in Figure 24 reads the pressure in a high-vacuum system directly with no computation or conversion factors. It has a double range, 0 to 20 microns and 0 to 0.75 mm. It is continuous in operation, and readings taken at any instant include the total pressure of the condensable vapors as well as the permanent gases that are present in the system.

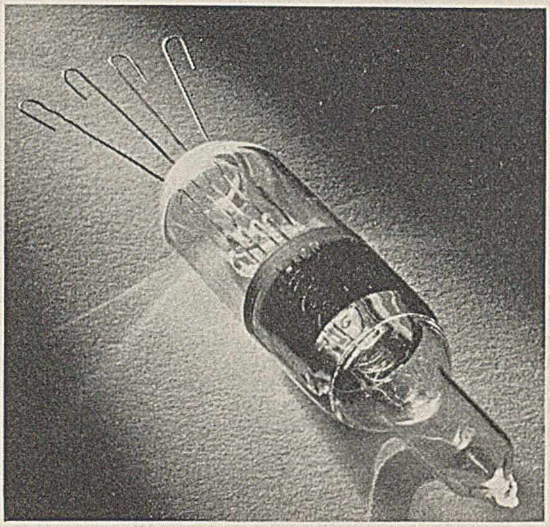
The gage proper consists of two carefully matched tubes fastened together by a clamp with a 9-foot cord connecting to the indicator unit. One tube is open, ready to be sealed into the vacuum line, and the other is permanently sealed off. The effect of ambient temperature is canceled by the proximity of the two tubes and their careful initial matching. A measurement is made by adjusting the filament to 3 volts (meter on the right) and then reading the pressure on either of the two scales which can be selected by the switch. Any zero shift which may arise from extended use, and which is due to a change in the radiation properties or resistance of the filament, may be corrected readily by evacuating the open Pirani tube to 10^{-4} mm. or less and re-adjusting the bridge balance. The operation is facilitated by using a McLeod gage as a standard, and a cold trap to eliminate condensable vapors.

The micron scale has a high sensitivity, 3 mm. per micron. The unit responds immediately to any change in pressure and hence may be easily adapted to the automatic control of vacuum systems.

IONIZATION GAGE. The ionization gage is one of the most sensitive devices for measuring very low pressures. The earliest types were little more than an ordinary triode sealed into the high-vacuum line. The necessary degassing was usually accomplished by electron bombardment of the metal parts and flaming of the glass envelope. The gage shown in Figure 25 was specially designed for pressure measurements and among its distinctive features is special provision for degassing of the elements.

The grid is in the form of a spiral and two leads are available, in order that this element may be heated electrically. By bringing the grid to incandescence for a few minutes it will be completely degassed. The plate is not introduced as a separate element but consists of a thin coating on the inside wall. Since the envelope is made of hard glass it may be safely torched with a flame, in this way driving occluded or adsorbed gas from the plate. Electrical connection to the collector plate is made with a glass-to-metal seal, which eliminates the usual danger of cracking at this point.

The principle of operation is similar to that of ionization manometers in general and an electrically heated filament serves as a source of electrons. The electrons are accelerated to the grid by a potential of about 100 volts. Residual gas is ionized by electron bombardment and the positive gas ions are drawn to the negatively charged collector plate. Over a considerable range the logarithm of the plate current is a linear function of the pressure. In this particular gage a sensitivity of 200 microamperes per micron may be assumed; thus a current of 20 microamperes denotes a pressure of 10^{-4} mm. Other values of grid voltage or plate voltage may be employed, depending on the conditions of operation and the value of the prevailing gas pressure.



Courtesy, Distillation Products, Inc.

FIGURE 25. IONIZATION GAGE

Numerous circuits have been described in the literature for operating ionization manometers. A number of them contain provision for automatically maintaining the grid current constant.

The ionization manometer has been used for many years, but the present offering is particularly welcome because it possesses so many convenient and distinctive features.

ROTAMETERS. The rotameter is a flow-rate meter of the variable-area type which accurately measures the flow of gases, vapors, or liquids. Gas or vapor flows of as low as 5 ml. per minute can be measured or, in industrial sizes, up to thousands of cubic feet per minute.

The essential part of a rotameter consists of a transparent tapered tube set in a vertical position with the large end at the top. Inside the tube is a plumb-bob shaped float which is supported only by the velocity head of the fluid stream which enters from the bottom of the tube. Graduations on the tube enable the observer to read the position of the float and hence determine the rate of flow. Rotation of the float is obtained by cutting slantwise slots in its head. The rotation helps to maintain the float in the center of the tube, and also serves to throw off dirt or bubbles which would otherwise change the calibration.

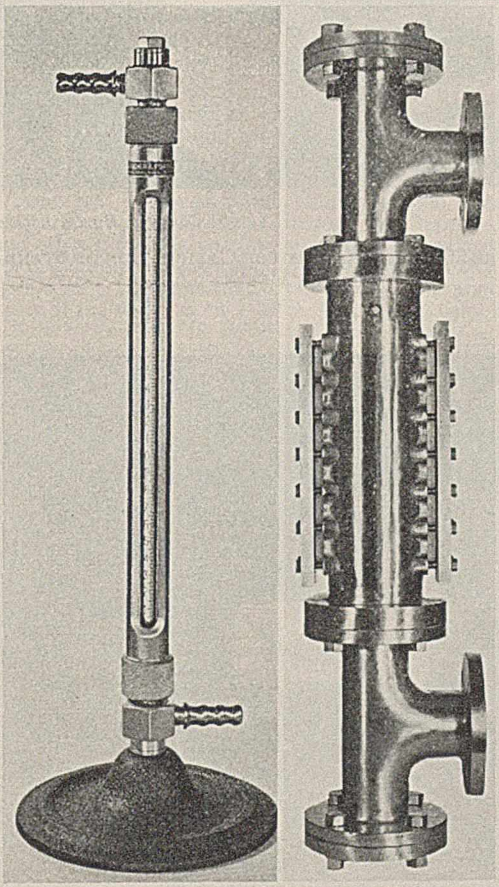
Figure 26 shows a laboratory model for very low flow rates and a large armored type for the industrial measurement of high flow rates. Pyrex tubes are used, although tubes of transparent plastic materials are also possible. A wide choice of materials is available for the floats, depending on the weight and desired chemical inertness. Steel and bronze are most common, although platinum, tantalum, silver, lead, glass, rubber, plastics, and aluminum have been used.

All the tapered glass tubes used in the Fischer & Porter rotameters—up to and including 4-inch size—are held to exact tolerances and are interchangeable, the tolerance being ±0.0006 inch for the largest tubes and ±0.0002 inch for others. The inner surface is mirror-smooth. The very uniform bore and taper are achieved by heating the glass to a semiplastic condition and shrinking it on an accurately ground and polished rotating mandrel. Careful annealing removes any residual strains.

The readability of these instruments is another advantage, since the graduations are uniformly spaced and not crowded together at one end as in orifice-type flowmeters.

Recently the use of rotameters has been greatly simplified by the development of a new float design which renders the flow readings independent of viscosity. Viscosities of fluids being metered may now be increased as much as tenfold without producing a noticeable error in the flow readings.

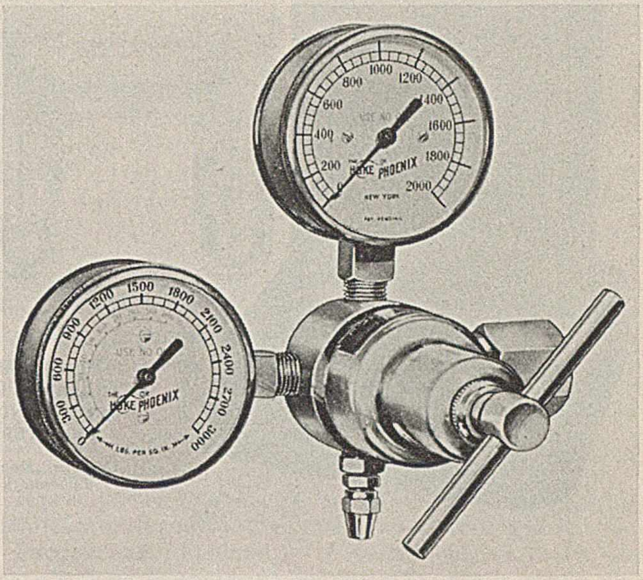
The many types of rotameters and diverse applications cannot be discussed here. Extensions of the general principle of the rotameter and accessories for remote reading and signaling are all discussed in the literature and in bulletins of the manufacturer.



Courtesy, Fischer & Porter Co.

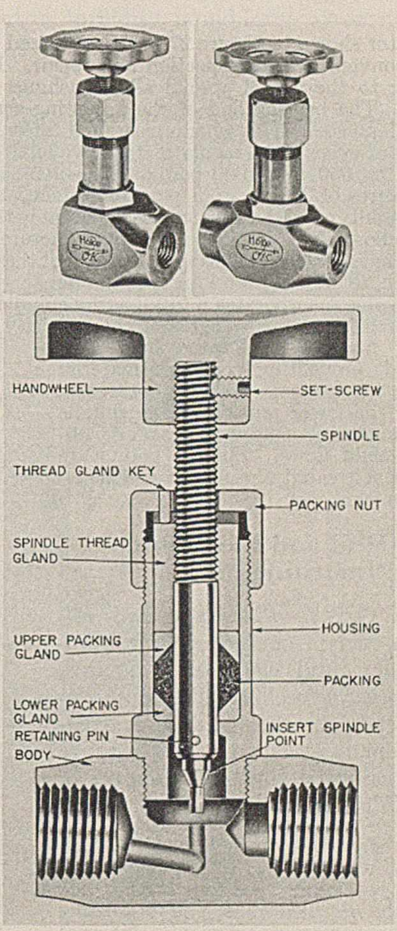
FIGURE 26. LABORATORY AND INDUSTRIAL STYLE ROTAMETERS

GAS REGULATORS AND VALVES. Within the last few years there has been increasing need for safe and convenient control of gas deliveries at high pressures. Higher pressures are being used in such applications as potential gum tests,



Courtesy, Hoke, Inc.

FIGURE 27. HIGH-PRESSURE REGULATOR



Courtesy, Hoke, Inc.

FIGURE 28. NEEDLE VALVE
Above, angle and straight patterns; below, cross section

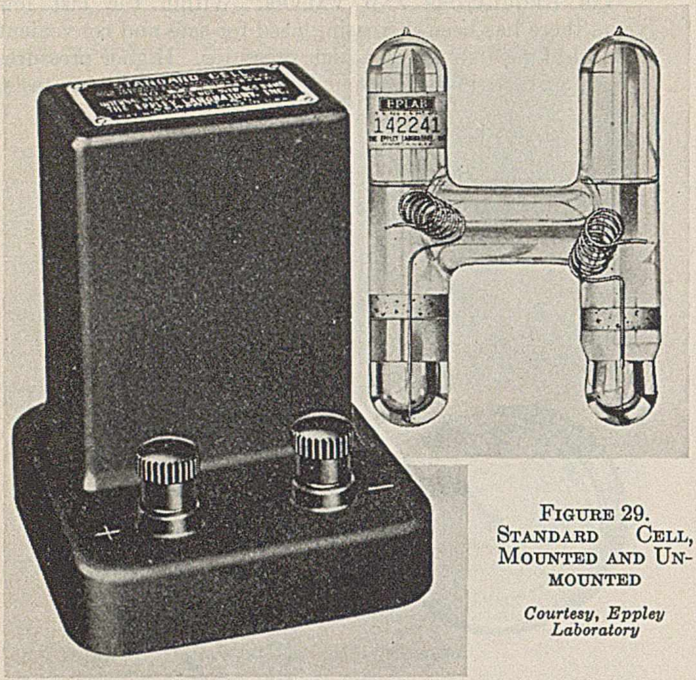


FIGURE 29. STANDARD CELL, MOUNTED AND UNMOUNTED

Courtesy, Eppley Laboratory

ultrafiltration, accelerated age testing, high-pressure hydrogenation, and bomb colorimetry.

The regulator shown in Figure 27 is characterized by low cost, safety, and convenience in inspection and repair. It is easy to adjust, owing to the use of special alloy bushings that reduce thread wear. The bearing end of the adjusting screw is fitted with a stainless steel ball which also facilitates adjustment. In two standard types these regulators are available for delivery pressures up to 550 and 1000 pounds per square inch and for cylinder pressures of 3000 pounds per square inch.

Some nice points of modern design are apparent in the corrosion-resistant needle valves of the same manufacturer. General views of the angle pattern and straight pattern of these valves are seen in Figure 28 (above) while a cross-sectional view is given below. The valve incorporates a full-floating spindle, the design of which is such that a high degree of concentricity is attained. The packing material is located below the spindle thread, preventing corrosive material from coming in contact with the threads. The taper of the lower portion of the spindle is 2°, affording ease of adjustment and control at small fluid flows. Spindle points are available in heat-treated chrome steel, Hastelloy C, and Z nickel.

Electrical and Electronic Instruments

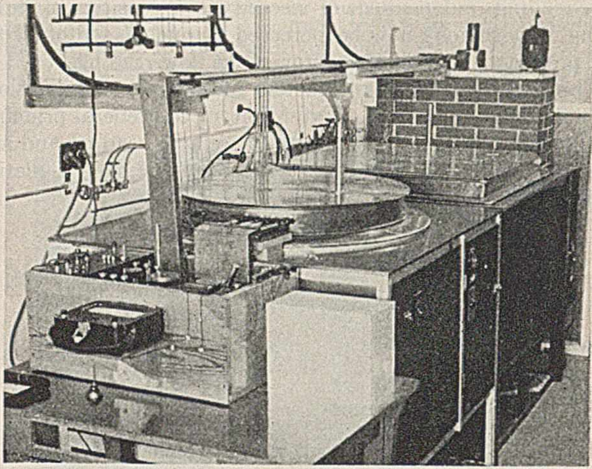
STANDARD CELLS. The standard cell continues to remain one of our most important fundamental electrical standards. Unceasing research seeks further improvements, but even the maintenance of existing internationally accepted values requires unremitting care and the best resources of instrumentation.

The standard cell shown in Figure 29, both mounted and unmounted, is the cadmium, unsaturated type, guaranteed to be within 0.01 per cent of the certified value and possessing a negligible temperature coefficient. Internal resistances are less than 500 ohms, but in another type at slightly higher cost cells may be had with internal resistances no greater than 100 ohms, these being specially adapted for use with deflection potentiometers.

Small details, which are incidental to the manufacture of these cells and not immediately apparent, contribute to the maintenance of these close tolerances—for example, the very careful purification of all cell materials, temperature-controlled annealing of the H vessels and their examination for residual strains in polarized light, and the use of plastic caps for protecting the lead-in wires.

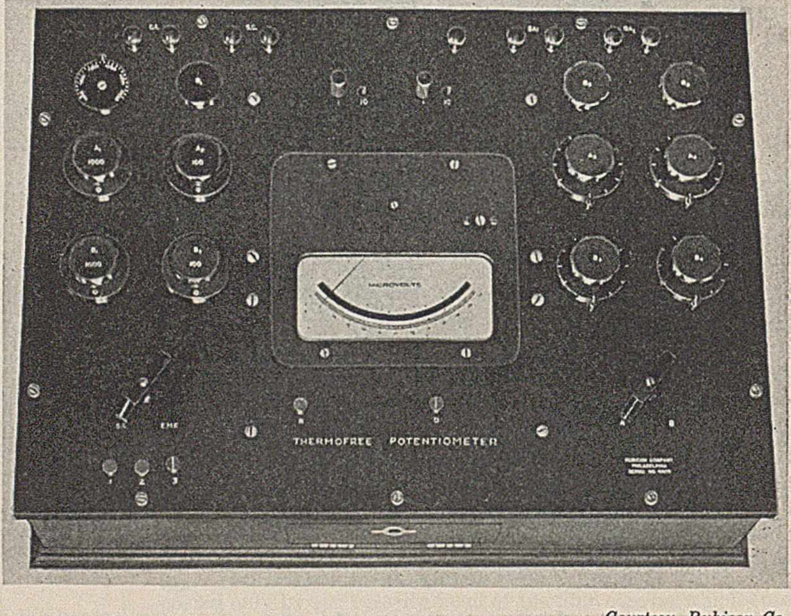
The checking of standard cells involves very elaborate equipment, and although the operation is incidental to the manufacture of commercial cells, the measuring equipment and precautions observed in its use are not excelled in any research laboratory.

Figure 30 shows the installation at the Eppley Laboratory. Two oil baths, heavily lagged, are so designed that no part of the metal of the bath in contact with the heated oil projects into the room, except the stirrer shaft. One bath will hold one hundred cells, completely immersed. Temperatures are read with a



Courtesy, Eppley Laboratory

FIGURE 30. LABORATORY FOR CALIBRATION OF STANDARD CELLS



Courtesy, Rubicon Co.

FIGURE 31. MICROVOLT DOUBLE-POTENTIOMETER

platinum resistance thermometer and a modified type of Mueller bridge, oil-immersed with temperature control. Regulation of temperature is within 0.01° C. A special type of potentiometer and an improved Feussner, both direct-reading, can be used for comparing the e. m. f. of the unknown with that of the standard. Difference measurements can be made by a modification of the method of Lindeck and Rothe (*20*), which is free of parasitics of thermal origin and introduces a net compensating potential from a local circuit, the current in which can be read on a microammeter.

RUBICON MICROVOLT DOUBLE-POTENTIOMETER. This instrument, shown in Figure 31, serves primarily for the accurate measurement of very low electromotive forces, the aim being to produce an instrument in which the residual e. m. f. of thermal origin should not exceed 0.01 microvolt.

Courtesy, G-M Laboratories, Inc.

FIGURE 32. TAUT-SUSPENSION GALVANOMETER WITH ENCLOSED LAMP AND TRANSFORMER

It involves the elimination of sliding switch contacts in the potential circuit, minimization of temperature differences at metal junctions, good thermal shielding, and use of the Wenner switch for reversing the galvanometer leads to estimate thermal residuals. These improvements have been discussed in publications from the National Bureau of Standards (*33*). These and other improvements are embodied in this instrument. Two decade dials cover 99 per cent of the range with an accuracy of 0.01 per cent. The remaining 1 per cent of the range is read on the scale of the meter from −10 to +110 microvolts (or decimal fractions thereof). The meter indications are based on the use of the Lindeck method. The model illustrated here is a double-potentiometer, which is especially convenient for measuring e. m. f. from two sources in rapid succession, without resetting the various controls. Provision is also made for measuring the potential of a difference couple by the deflection method.

GALVANOMETERS. Galvanometers are essential for numerous electrical measurements; they are necessary adjuncts to potentiometers and bridges. Dozens of types are available for special requirements, and of these we may mention one which has found numerous applications in the chemical field.

TABLE II. RANGES

(Weston Model 772 analyzer)

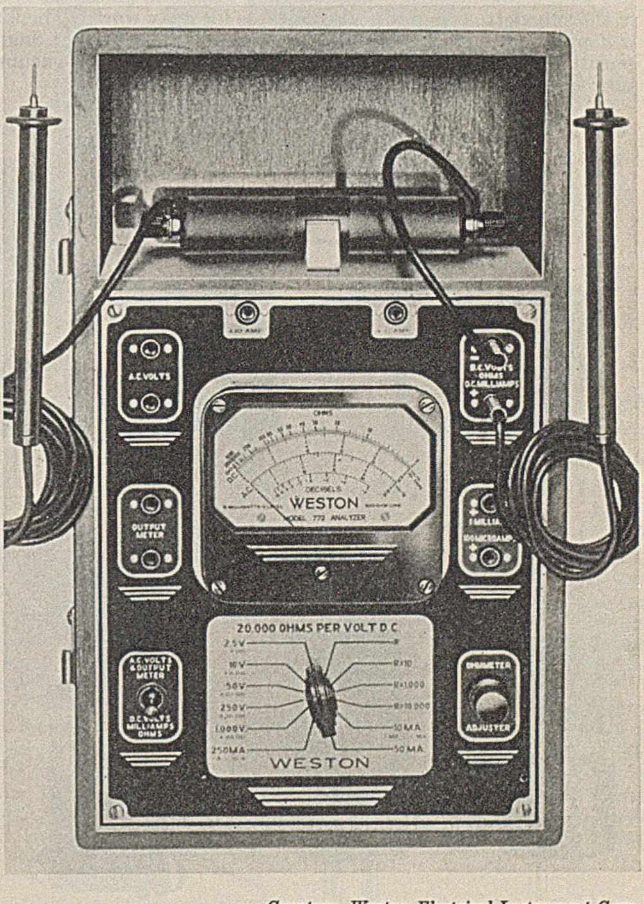
D. C. *Volts*	A. C. *Volts*	Current (D. C. Only) *Milliamperes*	*Decibels*	*Ohms*
2.5	2.5	0.1	−14 to + 2	0 to 3000
10	10	1	− 2 to +14	0 to 30,000
				Megohms
50	50	10	+12 to +28	0 to 3
250	250	50	+26 to +42	0 to 30
1000	1000	250	+38 to +54	
		Amperes		
		1		
		10		

As shown in Figure 32, it is of the taut-suspension type and is provided with lamp and scale. The galvanometer mirror projects a sharp black index line in an illuminated field on the translucent scale set at 45°. The model shown is provided with an enclosed transformer for operating the 6-volt lamp from the 110-volt alternating current line. Sensitivities range from 2×10^{-7} to 2×10^{-8} ampere per mm. division with coil resistances ranging from 22 to 1100 ohms. The coil period is 4 seconds for all ranges. The scale length is 80 mm. with a mirror-to-scale distance of 170 mm.

WESTON ANALYZER. There are frequent occasions in the laboratory when an electrical measurement is required and where a precision of a few per cent will suffice. Very often, little more than the order of magnitude is desired. To have suitable instruments for alternating and direct current voltages, for currents ranging from microamperes to amperes, and for resistances from a few ohms to megohms requires a considerable investment. Circuit analyzers similar to the one shown in Figure 33 are almost indispensable. With an accuracy of 2 per cent on direct and 3 per cent on alternating current, one can determine with this portable unit over a wide range the quantities indicated in Table II. The meter is a 50-microampere 4.25-inch instrument with a sensitivity of 20,000 ohms per volt on direct and 1000 ohms per volt on alternating current.

It is surprising to note how many first-class research laboratories are not equipped with instruments of this kind.

PHOTOTUBES. Phototubes of varied characteristics are manufactured in enormous quantities for use in sound pictures and numerous industrial applications, which include counting and sorting operations, spray-gun control for painting, illumination control, color matching, smoke measurement and control, turbidity, liquid level, pyrometry, registra-



Courtesy, Weston Electrical Instrument Corp.

FIGURE 33. CIRCUIT ANALYZER

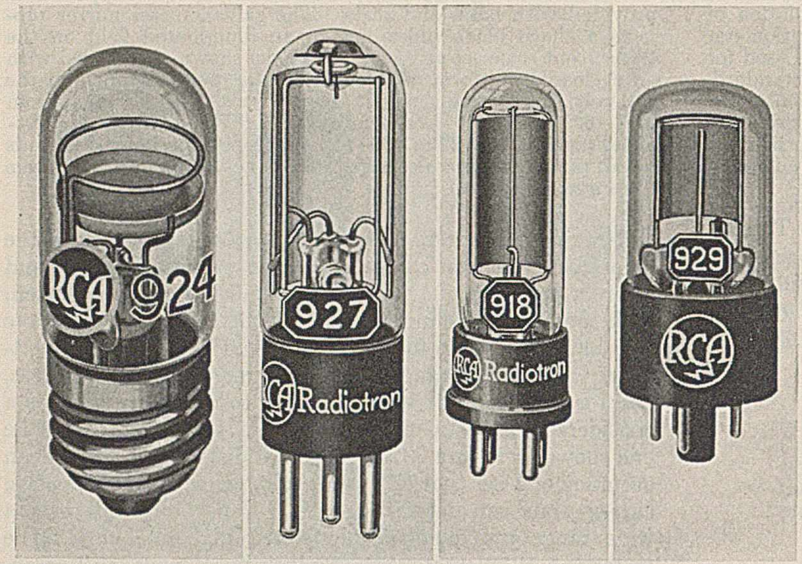


FIGURE 34. PHOTOTUBES *Courtesy, Radio Corporation of America*

tion control for printing or cutting paper, webstraightening control in textile machinery, etc.

Cells of almost any desired spectral characteristics can be obtained in glass, Corex, or quartz envelopes, of either the high-vacuum or gas-fitted type.

Some representative R. C. A. phototubes are shown in Figure 34. Although designed for more or less specific problems, they have many uses, suited to their particular characteristics. The 924 with screw-type base was designed for use in animated signs of the silhouette type; it is also suitable for relay work. The 927 is a small gas tube for sound-track pickup. The 918 is a high-sensitivity gas-type cell. The 929 is a new type of high-vacuum tube especially sensitive in the blue and near ultraviolet.

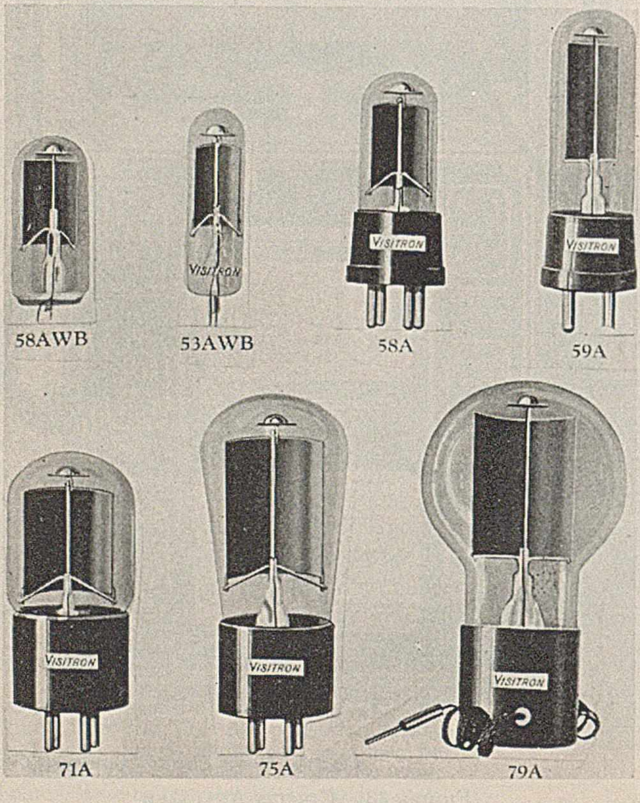


FIGURE 35. PHOTOTUBES *Courtesy, G-M Laboratories, Inc.*

The cells shown in Figure 35, made by the G-M Laboratories, cover a wide range of style, emitting surface, and spectral response. This company was one of the pioneers in the commercial production of photoelectric cells, and has made numerous special cells on request for photometric problems.

Manufacturers of these cells can supply complete data for all types, listing dimensions, nature of surface and envelope, spectral response, sensitivity in microamperes per lumen, operating voltages, and general service recommendations. It is not possible to reproduce all these data here.

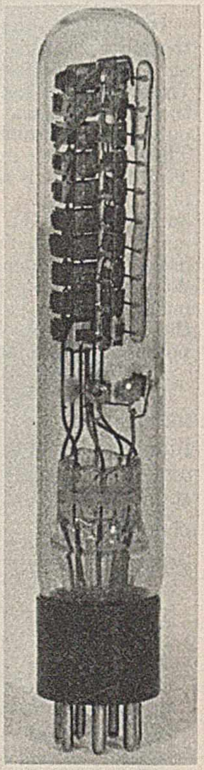
(For description of photoelectric controllers, see page 629.)

ELECTRON MULTIPLIER TUBES. More than 90 per cent of all photoelectric applications employ the emissive type of cell, usually with an appropriate amplifier. Since amplifier tubes are available in such profusion of style and characteristic, almost any application in the hands of an electronics expert requires little more than a careful and complete statement of the problem. Many years ago a photocell and amplifier tube were incorporated in one envelope by Zworykin. He and his co-workers at R. C. A. are largely responsible for the modern improved equivalent of this principle—the multiplier tube.

As shown in Figure 36, amplification of the primary photoelectric current is achieved by accelerating the photoelectrons to a sensitive surface, from which the primary photoelectrons eject other electrons; the phenomenon is known as secondary electron emission. This process may be repeated a number of times. In general, it is possible to eject 6 to 8 electrons for each primary electron and if we represent this number by S, then the amplification will be S^n for a multiplier tube of n stages. On this basis a multielement tube will have a response of the order of amperes per lumen! What this means, of course, is that very low light intensities—of the order of 10^{-6} to 10^{-8} lumen—can be measured with ease.

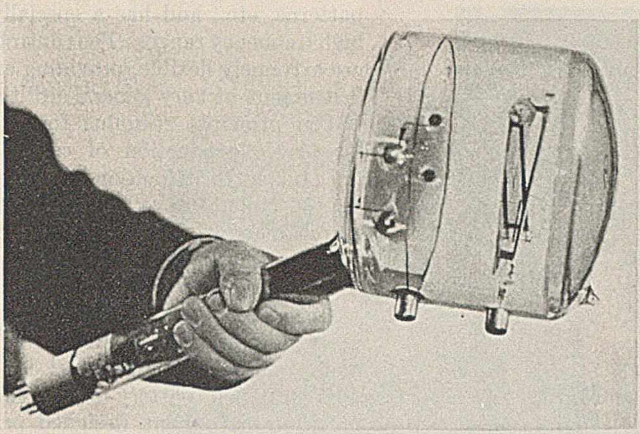
One very great advantage, aside from the compactness of the tube, is the fact that the signal-to-noise ratio is much greater than with the conventional phototube-amplifier combination—that is, in the measurement of low intensities, fundamental disturbances due to tube noises, random emission, shot-effect, etc., are less disturbing. Several tubes of this class are now in commercial production and will have considerable influence on instrument design of the future.

ICONOSCOPE. The iconoscope or image-forming tube shown in Figure 37 is the pickup unit used in television cameras. It consists of a photosensitive mosaic on which the image or picture is projected, which is then scanned rapidly by an interlaced sweeping beam of electrons. Thus each element of the picture is scanned and the light intensity of each minute



Courtesy, Radio Corporation of America

FIGURE 36. NINE-STAGE DEVELOPMENTAL TYPE OF MULTIPLIER TUBE



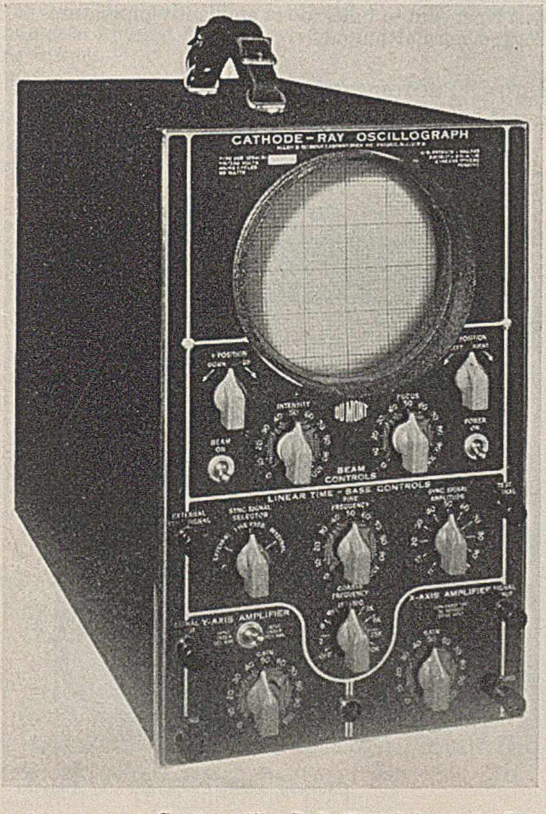
Courtesy, Radio Corporation of America

FIGURE 37. ICONOSCOPE

element of area is converted into a strictly proportional photocurrent. A device as useful and versatile as the iconoscope will not be restricted to television uses.

CATHODE RAY OSCILLOGRAPHS. The modern oscillograph is indispensable in the electrical and communication fields, but it is also widely used in industry and physical research. One of its chemical applications has been discussed by the author and his co-workers (*30*).

By means of the cathode ray oscillograph any quantity which can be translated into an equivalent electrical potential may be studied, usually on Cartesian coordinates as a function of any other variable. Recurrent phenomena may be studied as steady figures on the screen, and with the aid of photography the briefest of transients may be recorded.

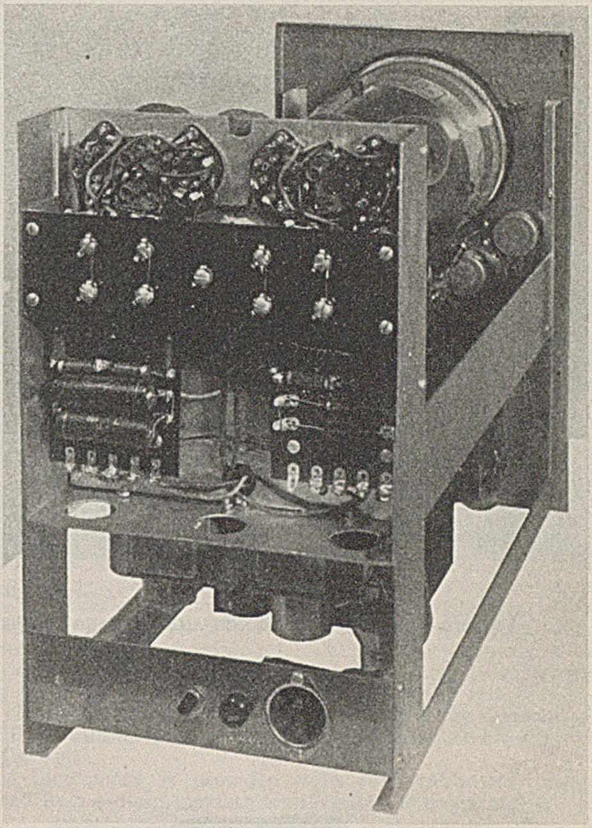


Courtesy, Allen B. DuMont Laboratories, Inc.

FIGURE 38. CATHODE RAY OSCILLOGRAPH

One of the latest types is shown in Figure 38. The tube is of the high-vacuum, electron-lens-focus type giving a high deflection sensitivity and sharp focus trace at all deflecting frequencies. The controls are all conveniently located on the front panel with related-function grouping. Separate amplifiers for the x and y axes are provided; the former is linear to 5 per cent from 2 to 100,000 cycles per second; the horizontal amplifier is uniform to within 10 per cent from 2 to 100,000 cycles. The voltage gains are: y axis 2000 ×, x axis 43 ×.

Figure 39 shows the rear chassis view, with short deflection plate leads. The terminal strip is accessible without removing the cabinet.



Courtesy, Allen B. DuMont Laboratories, Inc.

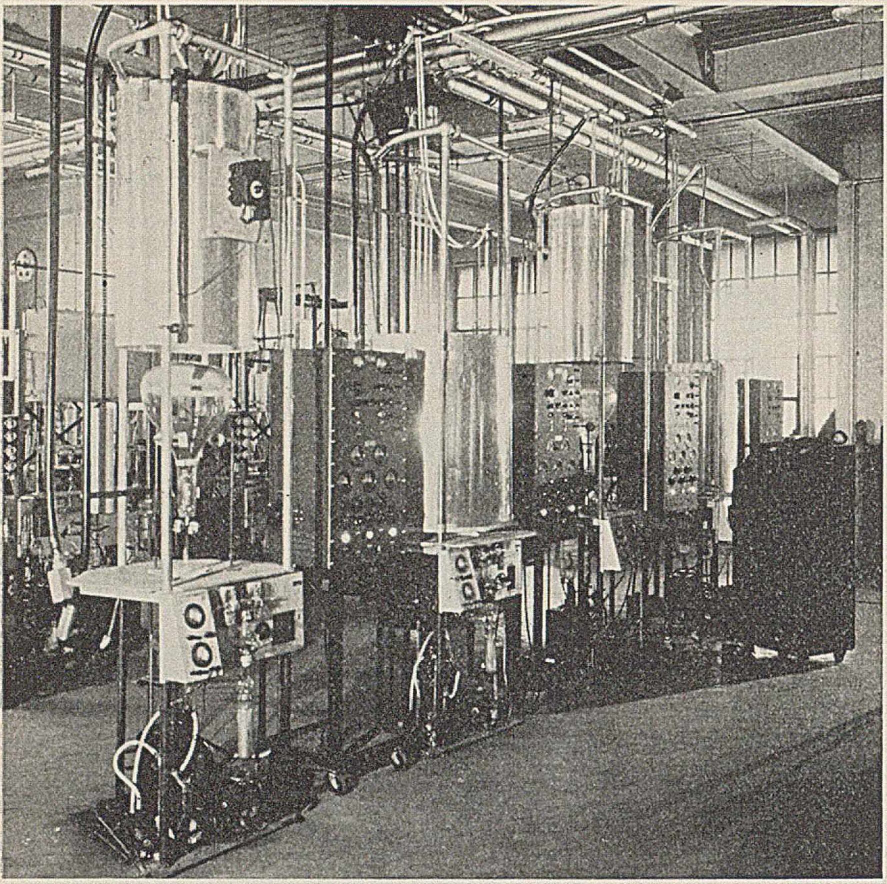
FIGURE 39. CATHODE RAY OSCILLOGRAPH, END VIEW OF CHASSIS

The production of cathode ray tubes involves the skilled techniques of high vacuum and electronics, and few better examples of modern instrumentation could be found than that shown in Figure 40.

The exhaust benches used by DuMont have a mercury diffusion pump at the base, backed by a Cenco Megavac forepump. On the extreme left of the pump table are the meters for the Pirani pressure gage. To the right of the master stopcock is the Variac control for adjusting the heater current of the oscillograph tube. To the right of this are switches for controlling the oil pump and a high-frequency bombarder (for heating the tube elements in vacuum to degas them).

The large cabinets to the right of each pump table contain complete circuits for checking and operating the tube while it is still on the exhaust bench. This includes power supplies for all the electrodes, appropriate meters, and signal sources of 60-cycle sine wave and variable-frequency saw-tooth sweep. Suspended above the tube on the first bench is the baking oven, thermostatically controlled for baking the screen material during exhaust and for annealing the glass.

R. C. A. OSCILLOGRAPH. The special 9-inch cathode ray oscillograph shown in Figure 41 is used primarily for tests involving television problems, for studying interlaced scanning



Courtesy, Allen B. DuMont Laboratories, Inc.

FIGURE 40. EXHAUST BENCH AND TESTING OF OSCILLOGRAPH TUBES

patterns, etc., and has a specially high frequency range. The controls are extremely flexible, providing an instrument of very general utility.

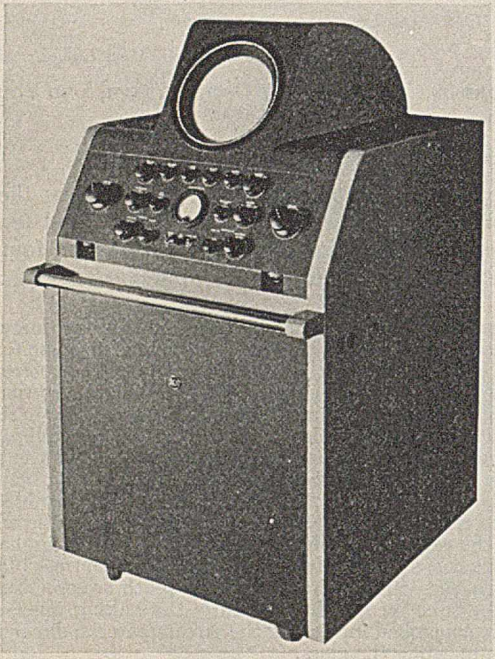
The principal stimulus for the large-scale production of cathode ray tubes is television—a very happy circumstance for the research man, who is thereby benefited by the availability of these useful devices at a moderate cost.

ULTRASENSITIVE DIRECT CURRENT METER. The electronic meter shown in Figure 42 is a self-contained battery-operated precision instrument, designed primarily for measuring very small currents.

It will also measure direct current voltages or resistances. It has 22 scale ranges. Currents between 2×10^{-8} and 10^{-2} ampere can be accommodated in 12 scale ranges. Over 8 scale ranges, direct current voltages from 0.1 to 500 volts can be read with a constant input resistance of 5 megohms. Resistances are covered in 2 ranges from 0.1 to 1000 megohms. With an external battery this may be extended to a maximum of 200,000 megohms. With the exception of the latter case, there is less than 0.5 volt direct current across the resistances. Three R. C. A. 1B-4 tubes are employed and the instrument weighs 20 pounds with batteries.

Some practical uses include the measurement of electron and ionic currents, photoelectric currents, electrolysis and galvanic currents, and others peculiar to electronic and radio circuit work. The accuracy is 2 per cent of full scale at ambient temperatures of 50° to 100° F. and normal humidity.

WESTON PHOTOELECTRIC POTENTIOMETER. This electronic self-balancing potentiometer (Figure 43) is very useful

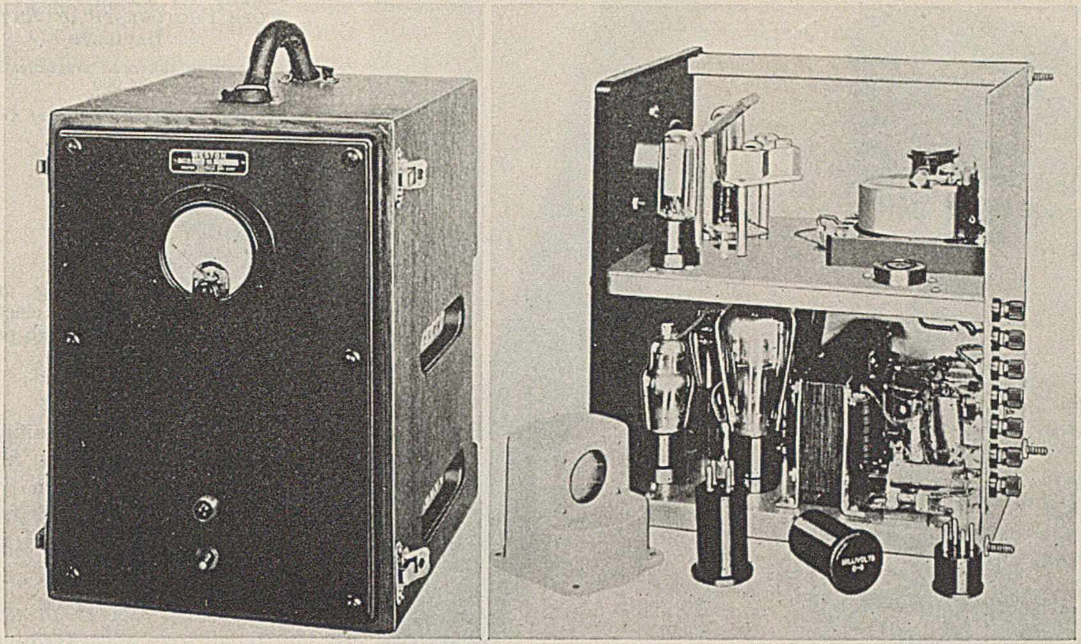


Courtesy, Radio Corporation of America

FIGURE 41. NINE-INCH SPECIAL CATHODE RAY OSCILLOGRAPH

Courtesy, Radio Corporation of America

FIGURE 42. ULTRASENSITIVE DIRECT CURRENT METER



Courtesy, Weston Electrical Instrument Corp.

FIGURE 43. PHOTOELECTRIC SELF-BALANCING POTENTIOMETER

for measuring small direct current voltages and currents. The principle of this instrument was described several years ago by Gilbert (*13*).

The usual potentiometer principle is modified in that, instead of moving a slider to select a suitable compensating e. m. f., the latter is derived from a standard resistor, the current through which is appropriately adjusted. This current is obtained from the plate circuit of a vacuum tube, the input of which is controlled by two phototubes in a bridge circuit. The phototubes are illuminated by light from a mirror galvanometer of negligible restoring torque.

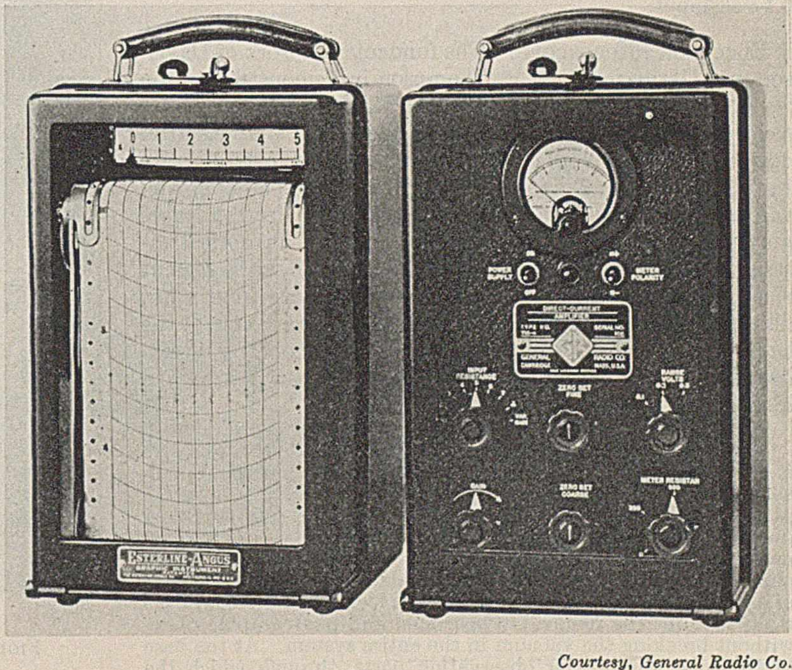
The galvanometer is connected in the primary potentiometer circuit. Imagine a small potential to be applied to the instrument. The galvanometer will tend to deflect slightly and illuminate one of the phototubes more than the other. The plate current of the vacuum tube will change immediately and cause a current to flow in the standard resistor just sufficient to restore balance. The plate current is directly proportional to the applied e. m. f. and is read on a suitable meter of the desired precision. The system is inherently stable and the usual variables—tube constants, plate voltages, etc.—are only secondary functions. A condenser-resistor network is applied to the tube input circuit to inhibit regenerative effects.

The range of the instrument may be changed by plugging in standard resistors. If desired, an automatic strip-type recorder can be operated at the same speed as indicating ammeter or voltmeter.

GENERAL RADIO CO. DIRECT CURRENT AMPLIFIER. The instrument shown on the right in Figure 44 was designed primarily for use with the Esterline-Angus 5-milliampere recorder. This amplifier should be of particular interest to the chemist because its characteristics are suited to the particular needs which many of his problems create. It is suited to the measurement of small potentials and currents and can be arranged to operate from photoelectric and photronic cells, frequency meters, resistance thermometers, etc.

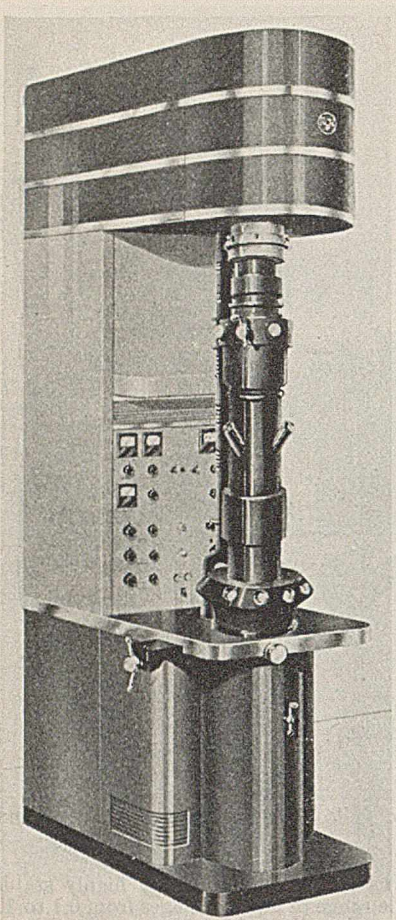
The amplifier is alternating current–operated, highly stable, and operating over a wide range of input voltages from 0.1 to 1.0 volt. Input resistances may be adjusted from 100 to 10 megohms. The tube circuit utilizes inverse feedback, an arrangement which assures a high degree of stability. The steady component of the plate current is balanced out by a bridge-type balancing network using a voltage-regulator tube, so that the meter indicates current change only. The voltage supply is carefully designed for stability of calibration, and will handle line variation between 100 and 130 volts.

The instrument is provided with four calibrated ranges, selected by a switch, yielding 5 milliamperes' linear output into



Courtesy, General Radio Co.

FIGURE 44. DIRECT CURRENT AMPLIFIER FOR USE WITH RECORDER



Courtesy, Radio Corporation of America

FIGURE 45. BIOLOGICAL ELECTRON MICROSCOPE

FIGURE 46. ELECTRON MICROSCOPE PHOTOGRAPH OF ANTHRAX BACILLUS

Photograph taken at magnification of 34,000

Courtesy, Radio Corporation of America

a recorder load of 1000 ohms for input voltages of 0.1, 0.2, 0.5, and 1.0 volt. The gain of the amplifier is best expressed as a transconductance—the maximum value of which is 50,000 micromhos—that is, 50 milliamperes' output per volt input, or better, within the range of the output meter, 5 milliamperes per 0.1-volt input.

ELECTRON MICROSCOPE. The fundamental work of Davisson and Germer and G. P. Thompson in demonstrating the wave nature of the electron, and of H. Busch and others on electron trajectories, gave rise to the subject of electron optics. Practically all of the theorems of geometric optics have been translated into the electron optics equivalents, and by means of magnetic and electric fields, electron lenses may be calculated to give the equivalent of an optical instrument such as the microscope. A simple arrangement of those elements enables one to focus electrons from a hot filament onto a fluorescent screen and obtain an image of the emitting surface. This very simple "microscope" is useful to metallurgists, radio engineers, and physicists in studying intimate details of electron emission.

In the handsome instrument shown in Figure 45, this principle is elaborated to the electronic equivalent of a compound microscope. Electrons from an electron gun can be focused in the plane of the object (mounted in an extremely thin film) and then imaged on a fluorescent screen or photographic plate. The magnetic and electric controls are all conveniently mounted on the panel and become the electronic equivalent of the focusing screw of a microscope. Convenient "pressure locks" are built into the main tube for the removal of specimen and photographic plate, without breaking the vacuum in the entire system. At the base of the tube are circular observation ports, through which the operator and a number of observers may view the image on the screen during focusing and adjusting operations. Elaborate electronic circuits maintain the applied high potentials constant to a high degree.

The available magnifications, with no loss of resolution, are orders of magnitude higher than those possible in optics. This arises from the fact that the wave length of an electron is given by

$$\lambda = \sqrt{\frac{150}{V}}\ \text{Å}.$$

Thus a 150-volt electron has a wave length of 1 Å. and a 40,000-volt electron, a wave length of 0.062 Å.

Figure 46 shows a photograph of anthrax bacilli taken at 34,000-fold

Courtesy, Radio Corporation of America

FIGURE 47. ELECTRON MICROSCOPE PHOTOGRAPH OF COLLOIDAL CARBON

Photograph taken at magnification of 110,000 magnification and Figure 47 shows colloidal carbon at 110,000-fold. The wealth of detail evident in these pictures is more startling than the unusual degree of magnification.

Courtesy, Bausch & Lomb Optical Co.

FIGURE 48. PROJECTION LENS WITH HIGH-TRANSMISSION FILM GLASS COATING

The electron microscope has been developed far beyond the stage of a mere scientific experiment and can be considered an important research tool. These instruments will be sought by many eager investigators, as they represent a means of obtaining information which has heretofore been entirely beyond the range of all other means of direct observation. In spite of the high state of development of these microscopes, experiments in the field of electron microscopy will be continued with the hope of eventually approaching more closely the ultimate resolving power of which these instruments are capable.

Optical Instruments

PROJECTION LENS WITH LOW REFLECTION LOSS. Researches in the properties of multilayer films have yielded information of importance to many fields. One of the useful, practical results has been the application of such films to the faces of optical components, minimizing the normal reflection losses. Figure 48 shows a high-quality motion picture projection lens in which the advantages of these films have been utilized. Fully 30 per cent increase in efficiency results from the use of such lenses and the general public has already been in a position to appreciate the improvements in some of the more recent motion pictures. No small part of the pictorial excellence of "Gone With the Wind" was due to the use of these lenses. The general principle is being widely applied to a variety of optical instruments and to the glass windows of electrical meters, etc.

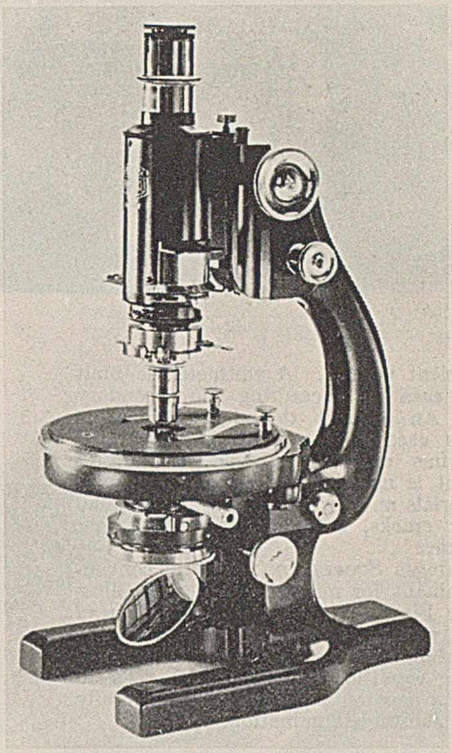
CHEMICAL MICROSCOPE. Especially helpful to chemists are the microscopes which have been designed specifically for their problems.

A typical example is illustrated in Figure 49, which shows the Spencer advanced chemical microscope. An important departure from conventional construction is the sliding tube analyzer instead of the usual cap analyzer. The enlarged field of view is very convenient and less fatiguing than some of the older small-aperture cap-nicols.

STEREOSCOPIC MICROSCOPE. This type of instrument (Figure 50) extends the range of natural vision by providing a complete microscope body for each eye with objectives and eyepieces to form the images.

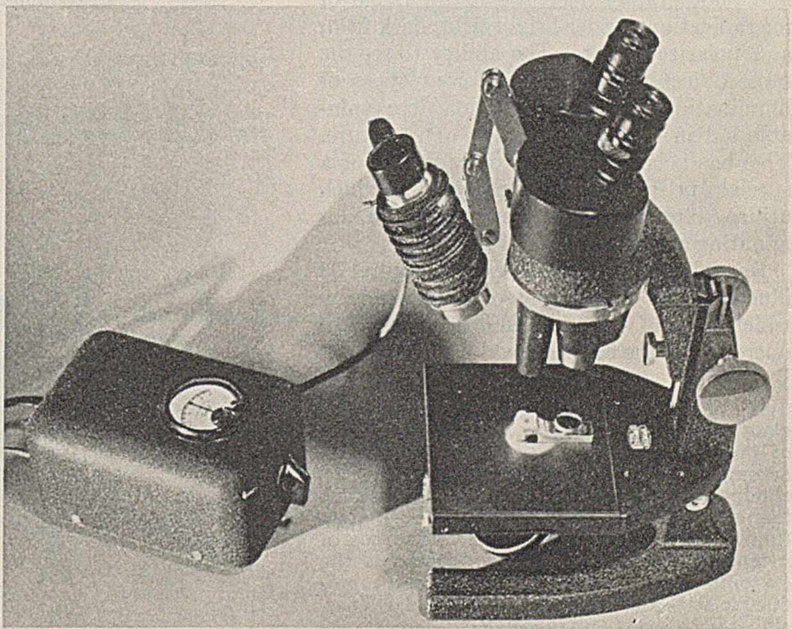
It has prism systems to provide the proper angle of inclination for the objectives to obtain stereoscopy and to ensure the proper angle of the eyepieces for comfortable vision. Objects may be magnified from × 6.3 to × 144. The image is right side up and not inverted nor reversed as in the monobjective microscope.

The instrument is shown with a light source providing reflected light. A 6.5-volt lamp is operated from a transformer with adjustable output permitting the bulb to be burned at its



Courtesy, Spencer Lens Co.

FIGURE 49. CHEMICAL MICROSCOPE



Courtesy, Spencer Lens Co.

FIGURE 50. STEREOSCOPIC MICROSCOPE AND ILLUMINATING UNIT

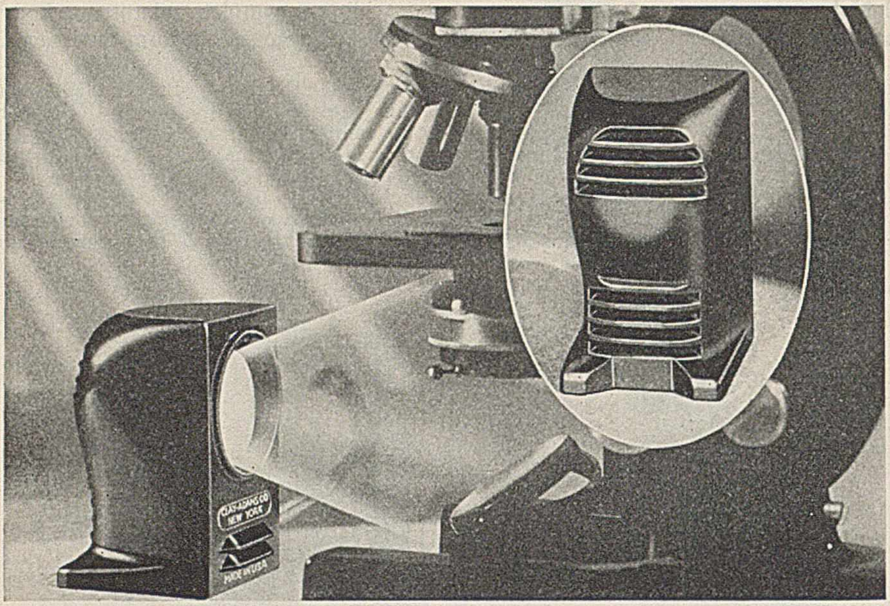
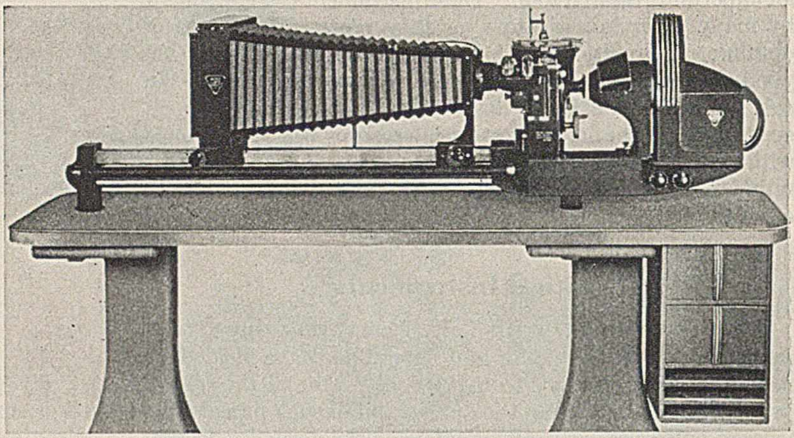


FIGURE 51. MICROSCOPE ILLUMINATOR
Courtesy, Clay-Adams Co.

most efficient voltage. A voltmeter is built into the case for measuring the secondary voltage. An efficient three-lens condensing system is used in the lamp and heat-dissipating fins carry away the heat. This instrument is useful for the examination of raw materials and for the inspection of small parts for cracks, flaws, scratches, or other irregularities.

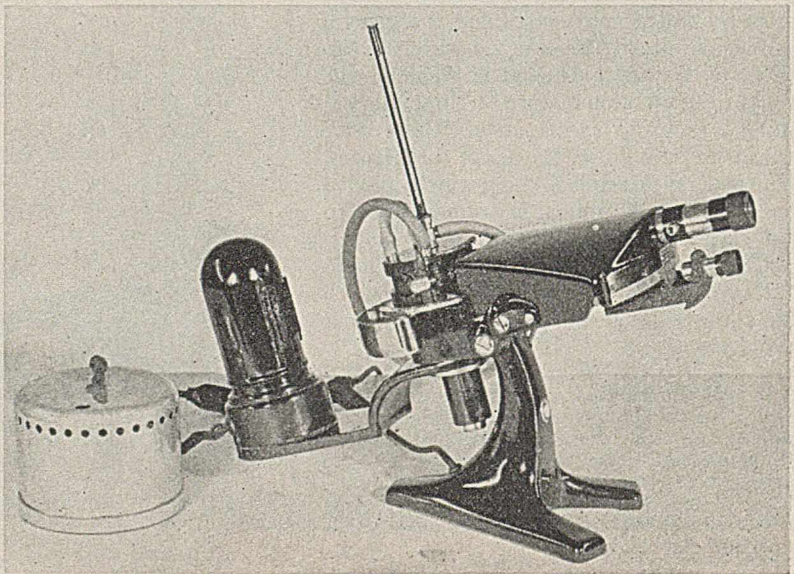
CLAY-ADAMS SCOPELITE. A very convenient illuminant for microscopic work is illustrated in Figure 51. Careful inspection of this unit reveals strictly functional design with location of the louvres for optimum ventilating conditions. It may be used in the vertical position as shown or horizontally for direct substage illumination.



Courtesy, Bausch & Lomb Optical Co.
FIGURE 52. RESEARCH METALLOGRAPHIC APPARATUS

RESEARCH METALLOGRAPHIC APPARATUS. The very modern unit shown in Figure 52 is a complete instrument for observation and photography over the entire range of magnifications under bright field, dark field, and polarized light. The ability to see the same object under these different types of illumination, without relocation, is a valuable aid in the interpretation of structure. This has been accomplished by means of a special prism-illuminating system which utilizes birefringence in separating the illuminating and observational beam.

PRECISION REFRACTOMETER. Figure 53 illustrates an instrument of high precision which retains the ease and simplicity of operation of the conventional Abbe type.

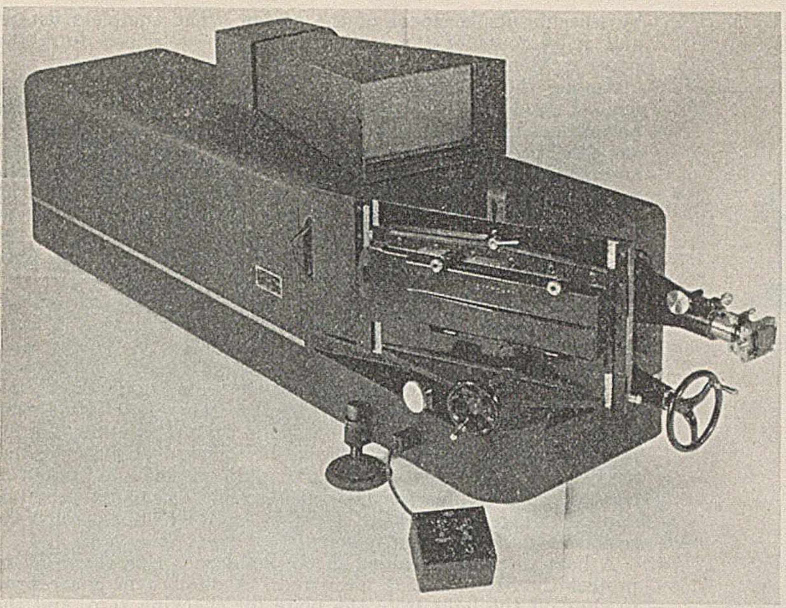


Courtesy, Bausch & Lomb Optical Co.
FIGURE 53. PRECISION REFRACTOMETER

It utilizes an oversized prism made of special glass specially treated to ensure uniformity of index. The improved precision has been accomplished by careful attention to the elimination of bearing errors, securing quick temperature regulation, and by the elimination of compensator error due to the use of a monochromatic light source, instead of the customary Amici prism. Readings are reproducible to 0.00003 for the C, D, and F lines, giving both index and dispersion.

The equivalents of this instrument are also available as a precision sugar refractometer and in a refractometer of higher range covering indices from 1.40 to 1.70, by utilizing a dense flint prism.

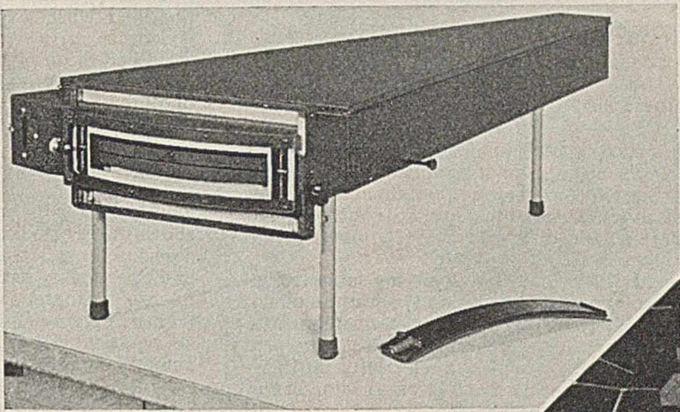
SPECTROGRAPHS. There are few instruments that have been as useful and essential as the spectrograph; a large portion of modern physical science is based on its revelations. The current trends, in extending its use to analytical and control work, are in the direction of simplifying its use without sacrificing precision or reliability. The modern instrument embodies so many improvements and skilled design

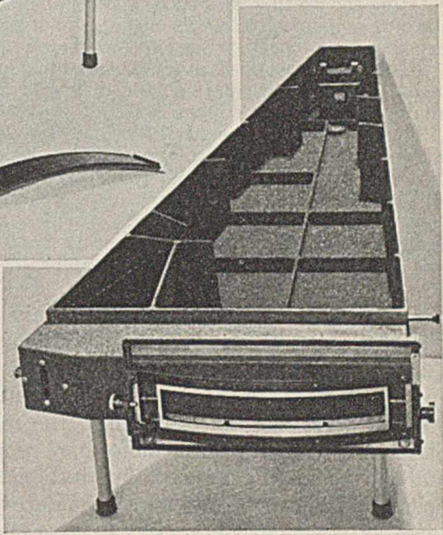


Courtesy, Gaertner Scientific Corp.

FIGURE 54. QUARTZ SPECTROGRAPH

features that one does not have to be a research physicist to obtain useful and trustworthy results. The instrument designer has undertaken the burden of making most of the necessary operations and adjustments automatic, thus relieving the operator of many time-consuming details. The importance of this can be realized if we recall that current industrial practice has reduced spectrographic analytical determinations to about 7 man-minutes per constituent. Some of these improvements can best be appreciated by considering the instrument shown in Figure 54.





Courtesy, Central Scientific Co.

FIGURE 55. GRATING SPECTROGRAPH

Lower right, cover removed to show ribbed baffling and mounting of grating

This spectrograph is of the two-lens type with Cornu prism, a design which eliminates many disadvantages of the Littrow autocollimating type. The base is a completely "normalized" casting of large section heavily ribbed. The enclosing case of sheet steel is large, to avoid interval reflections, and carefully baffled to assure complete freedom from stray light. The Cornu quartz prism is mounted in a metal housing for protection. A separate front surface mirror of high ultraviolet reflectivity replaces the reflecting surface of the prism which is characteristic of the Littrow instrument. The camera and collimator lenses are 75 mm. in diameter and are carefully figured from crystal quartz. The focal length is 1700 mm. at 5893 Å. The spectrum from 2000 to 8000 Å. is covered on two plates 14 inches long. The range 2200 to 3400 Å. can be covered on a single plate.

The prism and lens mounts are provided with dowel pins for location and are easily removable for cleaning or for the substitution of glass optics. Any desired spectral line in any portion of the spectrum, including the ends, can be brought onto the center of the plate, merely by turning the hand wheel. Besides giving the greatest flexibility to the instrument as a spectrograph, it permits ready adaptation of the instrument as a large monochromator to the method of direct photoelectric measurements of line intensities. Rotation of the hand wheel at the plate-holder end of the instrument accomplishes the change from one wave length to another. This operation automatically focuses the lenses, and rotates the mirror, prism, and plate to the correct position.

A very useful and convenient feature is the large illuminated scale which is projected on a ground-glass screen that shows the position of the system with respect to wave length. This indication is independent of the drive mechanism and any residual backlash or lost motion. The numbers are about 1 inch high and indicate wave lengths in millimicrons.

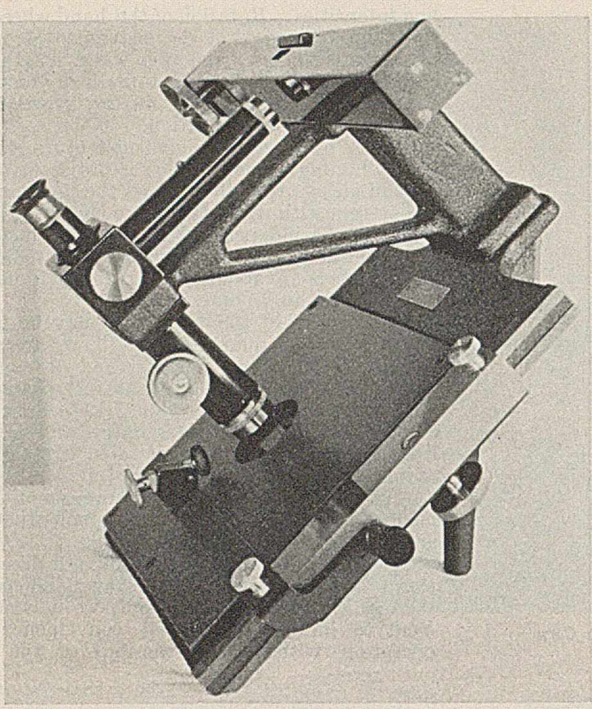
Glass optics of the same size may be substituted for the quartz optics. They are also carried in dowel-pin mounts, and are in accurate adjustment when thus interchanged. No other change in the system is necessary, for on substitution of the glass optics and wave-length scale the instrument is in completely automatic and continuous adjustment.

A shutter for timing the exposure is mounted behind the slit, leaving the latter unobstructed, and is operated by remote control.

Space limitations forbid a complete description of this instrument; it is available from the manufacturer. For our purpose it is sufficient to indicate the great convenience of operation without any sacrifice of the refinements which are regarded as essential in a first-class spectrograph.

The Cenco grating spectrograph shown in Figure 55 is a very useful low-cost instrument. It is suitable for qualitative and quantitative emission spectrography where a dispersion of 16 Å. per mm. is sufficient.

The spectrograph consists of a cast aluminum housing, well ribbed and baffled against stray light. The concave reflecting grating, 15,000 lines per inch and 106-cm. focal length, is of the Wallace replica type. The grating mount is fitted with adjusting screws for rotating the grating about the three principal axes and for shifting it laterally. Aperture masks provide a choice of either 14 or 6 exposures on a single film. The film holder or camera is provided with a vertical rack-and-pinion adjustment graduated and numbered for the 14 exposures. The first-order



Courtesy, Gaertner Scientific Corp.

FIGURE 56. SPECTRUM MICRODENSITOMETER

spectrum may be photographed between the limits of 2300 and 7000 Å. with a uniform dispersion of about 16 Å. per mm. By rotating the grating, any 4000 Å. portion of the spectrum between the above-mentioned limits may be photographed with a single exposure, the length of the exposure being approximately 25 cm.

A line of accessories is available including arc, arc control equipment, and a logarithmic sector disk and slit for quantitative analysis by Sullivan's method (*46*).

The instrument should fill a long-felt need for laboratories which cannot afford more expensive equipment, as an auxiliary unit for those already possessing high-dispersion instruments, and for educational institutions offering courses in spectrography. The manufacturer's Bulletin 107 provides much useful information on this instrument and a general introduction to some of the more recent references on spectrography.

DENSITOMETERS. Quantitative emission spectrography involves many factors, all of which limit the accuracy obtainable. Aside from the proper adjustment and use of the spectrograph one must consider the sensitivity of the photographic plate and its uniformity, the relationship between blackening and exposure, uniformity of plate development, and above all the conditions of excitation. Assuming that the operator has established an appropriate technique covering these variables, it is necessary to have some means for measuring the density of the lines recorded on the spectrogram.

Current practice ranges from the crudest visual inspection or "bracketing" of the observed density between densities obtained from standard samples, to use of the most elegant automatic densitometers. The academic investigator usually builds his own densitometer and he alone understands its caprices. Industrial practice and routine analyses require reliability and convenience of operation. We may consider three typical examples of densitometers possessing these requirements.

Gaertner Spectrum Microdensitometer (Figure 56). This visual means for measuring the density of photographic images is an improvement of the well-known Hartmann microphotometer. It is based on the principle of dividing a beam of light from a milk glass, one beam passing through the photographic plate, the other through a neutral wedge. The two beams are recombined in a photometer cube and may be matched for intensity by suitable displacement of the wedge. The complete details and refinements of the instrument are best gained from the paper written by the designers (*18*).

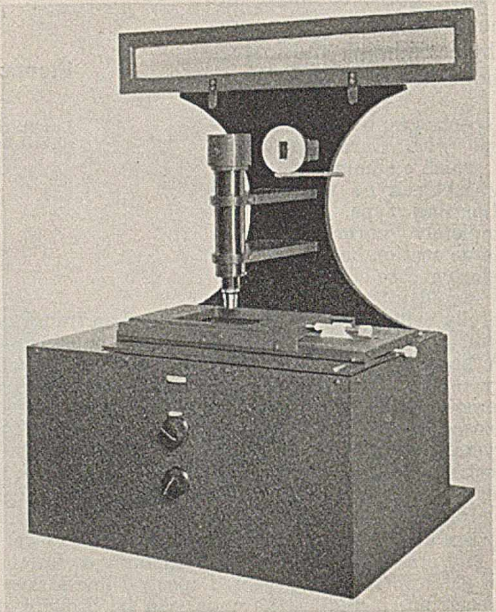
Among the improvements may be mentioned the use of a neutral dyed gelatin wedge of 10-cm. length following a linear law of densities ranging from 0 to 4.0; the use of grain plates to simulate the natural graininess of the photographic plate; and elimination of the sliding cube of Hartmann, by using a silvered strip in the cube to reflect the field of the wedge and its grain plate. The instrument is a very useful accessory for quantitative spectrographic analysis. It has been applied to the study of x-ray diffraction patterns produced by cellulose fiber (*43*).

General Electric Transmission Photometer for Spectrograms. The instrument shown in Figure 57 consists of a housing containing a 6-volt, 18-ampere projection lamp, condenser lens, and high-aperture lens which throws a uniform circular spot of light on the plate to be measured. The latter is held in a mechanical stage arranged to move in three directions, facilitating easy adjustment of focus and location of the field to be measured. A high-quality objective gives a twentyfold magnified image of this field on the rectangularly shaped diaphragm which is located in front of the G. E. barrier layer photocell. The photocurrent is applied to a galvanometer, the deflection of which is read on the scale at the top of the instrument.

A heat filter is contained in the condenser lens assembly to protect the sample being measured. A diaphragm is arranged to shut off the light from the plate for checking zero, and the total intensity of the light can be varied over a small range for the adjustment of full-scale deflection. There is also provision for the introduction of a neutral filter to change the total amount of light reaching the photocell in known ratio. All these controls are conveniently located on the front of the instrument.

The diaphragm defining the portion of field being measured is provided with several apertures, the smallest of which corresponds to an area on the plate of 0.001 × 0.037 inch. Full-scale deflection of the galvanometer, at 1-meter distance, under these conditions is about 500 mm. Angular adjustment of this diaphragm permits accurate alignment with the projected spectrographic line. A storage battery of sufficient capacity is required for the light source, or a step-down transformer operated from a voltage-regulating transformer.

Leeds & Northrup Recording Microphotometer. The most elegant solution of this problem to date is the microphotometer shown in Figure 58. The equipment consists of the plate stage, associated driving mechanism, optical system, and the amplifier and Speedomax recording unit (described below). As a recording microphotometer it is characterized by high speed of recording (continuously visible during the process) and a record width (25 cm. maximum) which is very large compared to that of other available recording instruments. The pen record is obtained



Courtesy, General Electric Co.

FIGURE 57. TRANSMISSION PHOTOMETER FOR SPECTROGRAMS

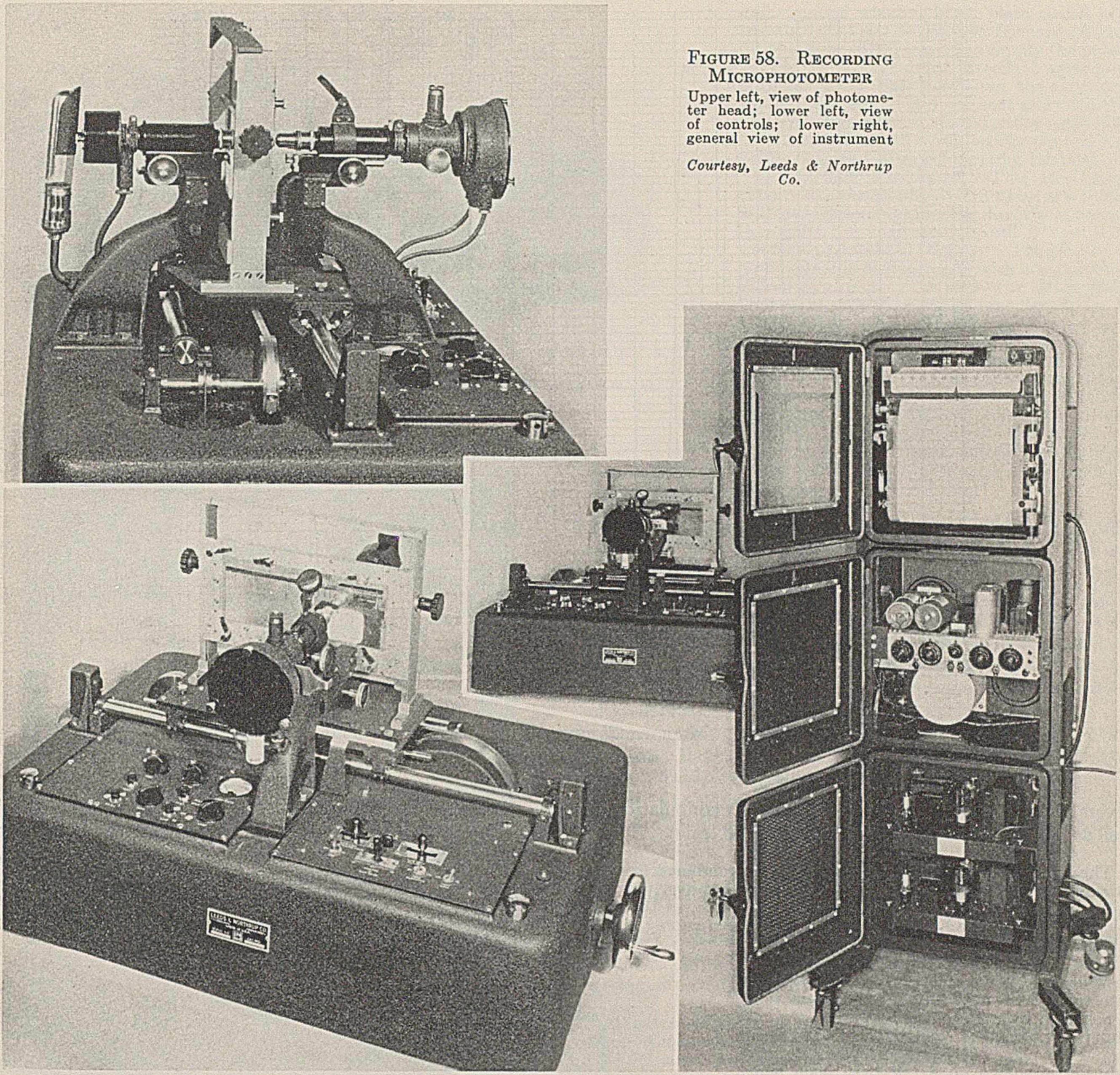


FIGURE 58. RECORDING MICROPHOTOMETER

Upper left, view of photometer head; lower left, view of controls; lower right, general view of instrument

Courtesy, Leeds & Northrup Co.

without development or delay. The accuracy is 0.25 per cent of full scale and the response is strictly linear (*12*, *19*, *25*).

The optical unit follows the general principles of microphotometer design but with many distinctive features. The plate carriage may be driven horizontally by a hand crank or synchronously by motor drive with a choice of nine speeds yielding an equal number of ratios of plate travel to recorder chart travel. The speeds range from 0.1 to 40 mm. per minute with corresponding ratios of chart to plate travel of 500:1 to 1:1. Adjustable limit switches are provided for stopping the carriage as well as the chart motion.

The source of illumination is a special ribbon-filament lamp with optically flat windows. A microscope objective projects an image of the filament upon the emulsion. A second objective projects the transmitted light into the photometer head containing the carefully insulated and shielded vacuum-type photocell (Figure 58, upper left). The output of the photocell is fed to a direct current preamplifier mounted in the plate stage and the output is then applied to the Speedomax recorder.

Power packs supply filament and plate voltages for the preamplifier and Speedomax amplifier, which are constant for alternating current line voltages between 90 and 115 volts, independent of frequency changes.

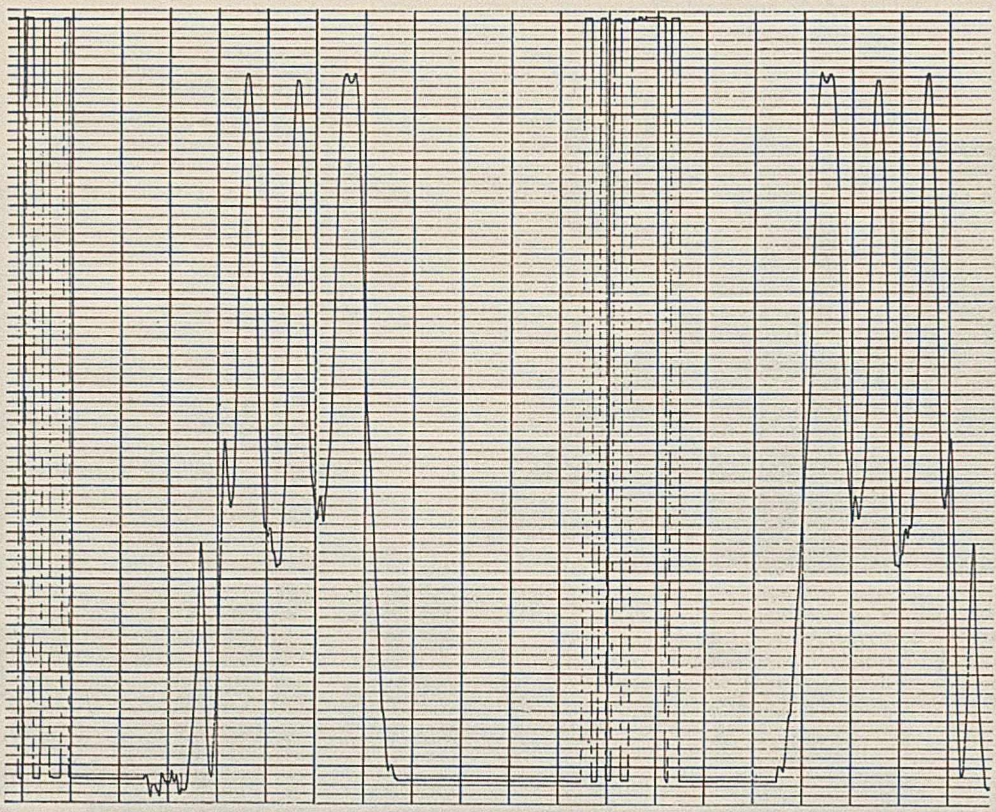
As an unequivocal criterion of speed of response the manufacturers have chosen a true sinusoidal light variation of 5-second period. At full scale the recorder will reproduce this curve to 0.25 per cent or better. Translated into actual microphotometer practice, a plate taken with a large quartz spectrograph with an 8-micron slit can be run at 2 mm. per minute without introducing errors due to recorder lag. No difference is found at lower speeds, while at higher speeds, particularly with sharp lines, lower density values may be indicated.

All necessary controls are conveniently centralized (Figure 58, lower left) for rapid adjustment.

The sample chart shown in Figure 59 for the resolution of the Fe triplet at 3100 Å. (Fe = 3099.971, 3100.309, 3100.671 Å.) gives an excellent idea of the performance of this instrument. Note the steadiness of the base line and the remarkable fidelity of the trace on the right, obtained by reversing the direction of plate travel.

It is an interesting commentary on the versatility of the Speedomax recorder, that it can accomplish such a delicate and exacting task with speed and precision, as readily as it can record the temperature of white-hot steel ingots in a rolling mill.

SPENCER DIRECT-RESULT COLORIMETER. This modern version of a well-known instrument (Figure 60) embodies



Courtesy, Leeds & Northrup Co.

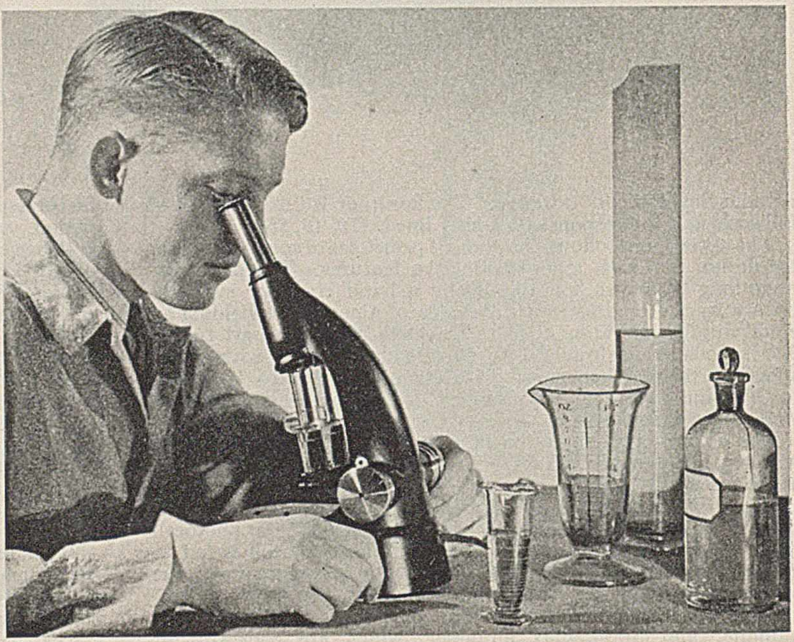
FIGURE 59. MICROPHOTOMETER RECORD OF 3100 Fe TRIPLET

several improvements and conveniences in manipulation as well as important simplifications in the optical train.

The light beams from the two plungers are combined in a biprism which forms the sensitive dividing line between the two fields. The plungers are inclined at a slight angle, so that the lower ends enter the liquid obliquely to provide a wiping action which effectively cleans bubbles and scum from the lower surfaces. The direct-reading feature, in which the percentage concentration is read directly without need for tables or calculations, is achieved by a mechanism in which the rack and pinion drive moves the graduated drum through a planetary gear. The depth of each solution is shown on a two-part scale which reads units on the number ring and fractional parts on the drum. Either side of the colorimeter may be used for the standard, since the scales are identical, by setting the sample at 10.00 (which corresponds to a depth of 40 mm.) and then adjusting the depth of the standard in order to match the color fields; the scale on the standard side, when multiplied by 10, shows directly the percentage concentration of the sample. The scales are graduated in units from 0.00 to 14.00, giving the colorimeter a range of 0 to 140 per cent.

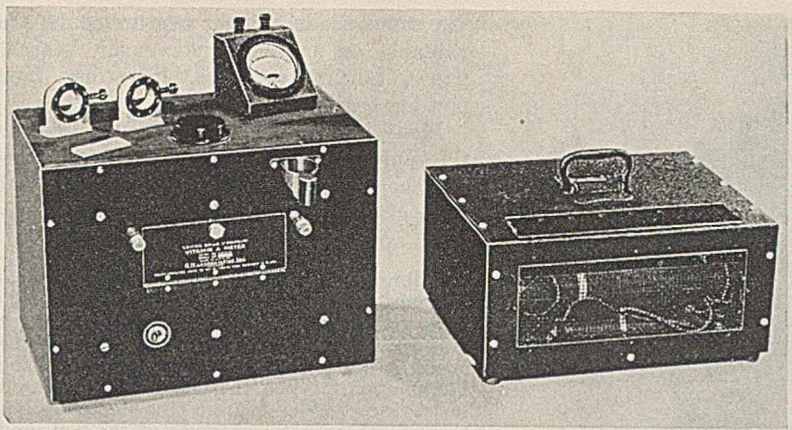
Innovations are to be found in the cups, which consist of four parts: cup body with threads molded into the glass, gasket of chemically resistant synthetic rubber, glass bottom plates, and threaded cap of molded plastic. The cap and bottom plates are carefully standardized for thickness, resulting in interchangeability without affecting the zero points of the scales. The illuminator is built in as an integral part of the instrument base with diffusing windows set flush with the top of the base. Illumination equalization is achieved by a simple control which may be locked to prevent accidental displacement. The general appearance bespeaks modern simplicity and convenience.

PHOTOELECTRIC PHOTOMETERS AND "COLORIMETERS". This subject was reviewed by the author last year (*29*), when an incomplete bibliography listed 263 references. Relatively few advances have been made recently on the instrumental side, but more important is the extensive use to which these instruments have been put in analytical work. Photoelectric



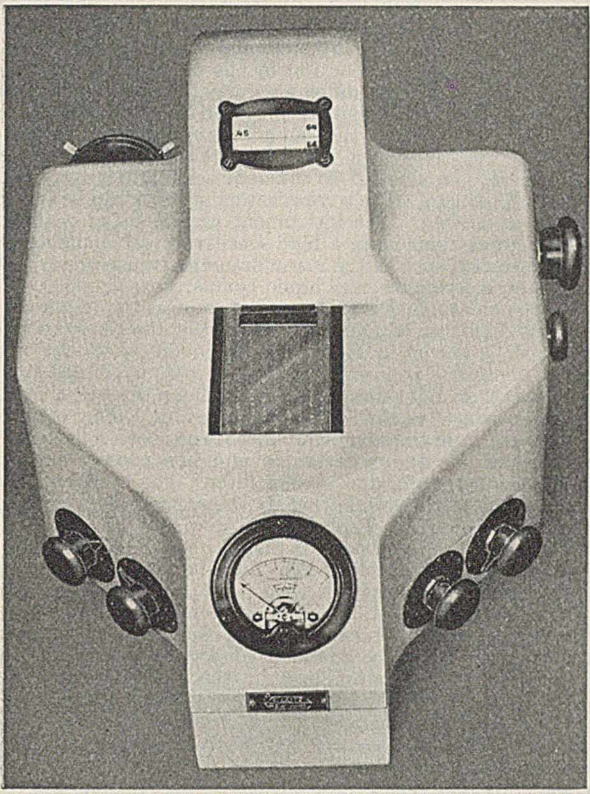
Courtesy, Spencer Lens Co.

FIGURE 60. DIRECT-RESULT COLORIMETER



Courtesy, G-M Laboratories, Inc.

FIGURE 61. VITAMIN A METER



Courtesy, E. Leitz, Inc.

FIGURE 62. PHOTOELECTRIC PHOTOMETER

photometers are replacing visual instruments to an increasing extent. It is significant that with improved instruments available, more and more of our standard colorimetric methods are being reexamined for their reliability.

The notion that photoelectric spectrophotometers will soon displace all filter photometers seems to be gaining ground; actually at the present state of development, most of our analytical colorimetric methods hardly justify the use of a good filter photometer. The respective uses of the two instruments are still well defined and improvement in each is still possible.

Vitamin A Meter. This instrument, illustrated in Figure 61, has been described by McFarlan *et al.* (*23*). It is a twin-cell photoelectric photometer with optical compensation. The source of illumination is a sodium arc with filters to isolate the sodium doublet at 3303 Å. The net photocurrent is indicated on a 0–5 milliammeter which is in the plate circuit of a two-tube amplifier designed by Shepard. An additional tube (6H6) is used to supply the potentials to the phototubes. Excellent agreement is obtained by Beer's law and the extinction values are accurate to 1 per cent and with care to about 0.5 per cent. Satisfactory agreement has been obtained with spectrophotometric values obtained from cooperating laboratories.

Leitz-Müller Photometer. This instrument (Figure 62), designed by the author, is a single-cell filter photometer reading directly in extinction units. A high-vacuum cell is used with a two-stage stabilized amplifier. The phototube input signal is balanced out with a logarithmic slide-wire circuit. The slide-wire drum reads directly in extinction values (one decade for 17 inches of scale). Selective filters are mounted on a wheel, and all electrical and mechanical adjustments are interlocked for speed of operation. As each filter is selected, an appropriate phototube load resistor is automatically selected to yield approximately uniform sensitivity. Interchange of solution and solvent is achieved by a rotary carriage drive also interlocked for electrical adjustments. Extinction values between 0 and 1.0 are reproducible to ±0.001.

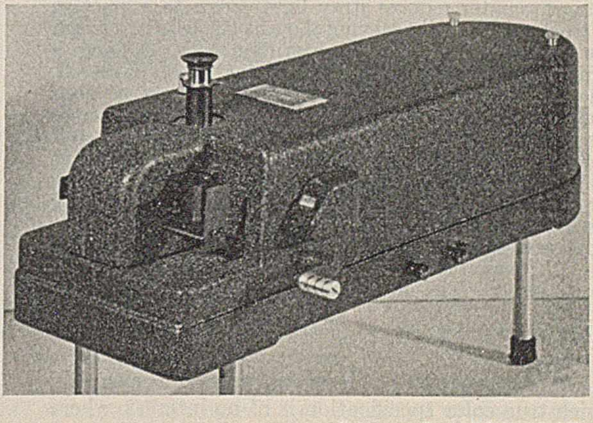
PHOTOELECTRIC SPECTROPHOTOMETERS. "It is generally recognized that accurate spectrophotometric data, when accompanied by adequate colorimetric computations, comprise the most fundamental of all colorimetric specifications" (*12*).

The advantages of a photoelectric instrument are speed, elimination of fatigue, and improved precision at the extremes of the visible spectrum. The mistaken notion still exists, in the minds of some, that spectrophotometry was not exact and reliable until photocells "replaced the human eye".

The recording photoelectric spectrophotometer or "color analyzer" developed by Hardy and manufactured by the General Electric Company is now so well known and so widely used that no description of it need be undertaken here, except to note that it is still the only completely automatic instrument of its kind.

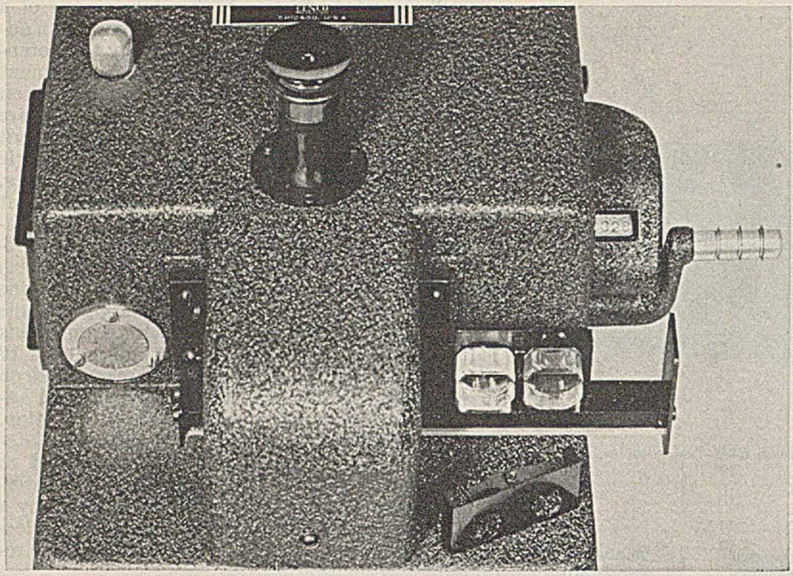
Two recent developments of the manually operated type will be discussed briefly. Figures 63 and 64 show the Cenco-Sheard spectrophotelometer. This instrument augments and extends the field of measurement beyond that which is possible with their photelometer, a filter photometer which is widely used in clinical and other "colorimetric" methods of analysis.

An external source of light, operated from a constant voltage source is focused on a slit, the light passing on to a Wallace concave diffraction grating replica of the reflecting type. The latter diffracts and projects the spectrum to the opposite end of the housing where, depending upon the position of the grating, it focuses a portion of the spectrum on exit slits having nominal slit widths of 2.5, 5, 10, or 20 millimicrons and thence to a barrier-



Courtesy, Central Scientific Co.

FIGURE 63. SPECTROPHOTELOMETER



Courtesy, Central Scientific Co.

FIGURE 64. SPECTROPHOTELOMETER
Showing wave-length scale, absorption cells, and slit adjustment

layer photocell. A crank on the side of the housing slowly rotates the grating and maintains the focus automatically as different portions of the spectrum are brought to the exit slit. A revolution counter indicates the prevailing wave length directly (shown at λ = 328 millimicrons in the photograph). An eyepiece in the top of the case enables the operator to see that portion of the spectrum so selected. When used with a line source such as a mercury arc, this eyepiece affords a convenient check for the accurate functioning and alignment of the optical system.

The terminals of the photocell are connected to an external, enclosed-lamp-and-scale galvanometer.

A two-cell carriage is mounted between the exit slit and the photocell for holding absorption cells, one for the solvent, the other for the solution. Transmissions at any wave length are given by the ratio of the galvanometer deflections for solution and solvent, the latter usually being set at 100 for convenience.

The instrument is carefully baffled and shielded to avoid errors due to stray light. Careful measurements made with this instrument have shown good agreement with values reported using other types of precise spectrophotometers.

Another approach to this problem is shown in Figure 65. The Coleman double monochromator spectrophotometer consists of two units. The first contains the light source, double monochromator, absorption cell holder, high-vacuum photocell, and a 4-decade photocell load resistor. The potential drop across this resistor is measured by the standard Coleman electron tube potentiometer.

Two echelette gratings and a total reflecting prism are mounted on a cam and lever system, so that rotation of the cam, to which a uniform wave-length scale is attached, will bring any desired portion of the spectrum on the exit slit. The use of a double monochromator reduces stray light errors to a fraction of 1 per cent. Light leaving the exit slit passes through one or the other of the absorption cells, striking a diffusing disk which uniformly illuminates the photocell. The load resistor for the photocell consists of four decade units in series. The potential developed across the total resistance is measured by the potentiometer. For the reading of the solvent, the decade is set at such a value that the potentiometer balances at unity (or if a pH meter is used, at pH 10). Upon introducing the test sample in the light beam, the potentiometer is rebalanced giving the transmission directly. Thus if the pH meter read 8.3, this would indicate 83 per cent transmission. The electrometer can be read to 0.1 per cent.

Figure 66 shows some representative results.

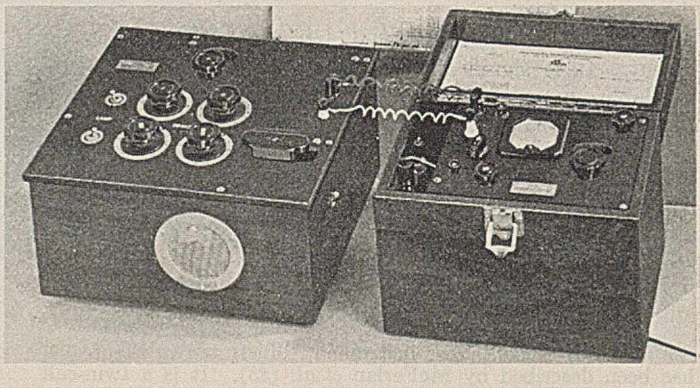
REFLECTOMETERS. There are many problems in which true color specification is of no interest, where it is merely necessary to compare samples with a standard of the same nature to see if they possess the same shade. Such measurements are valuable on products like sugar, starch, paper, fabrics, ceramics, limestone, face powder, soap, etc.

Many instruments have been devised for this purpose; the two which we shall discuss here are commercially available and have given satisfaction in a number of diverse applications.

Figure 67 illustrates the Universal reflectometer made by Pfaltz & Bauer. A barrier-layer cell is used as the light-sensitive element and is mounted in the same housing as the small incandescent lamp which supplies the illumination. When the entire unit is placed on a sample, light from the lamp passes through the central aperture of the cell, and is reflected by the sample onto the active surface of the cell. The photocurrent indicated by the microammeter is a measure of the light reflected by the sample. The meter-unit is also provided with a built-in compensating unit. With its use, the photocurrent obtained by reflection from a standard white plate or other comparison standard may be set at 0 or 100 by the compensation network. Smaller differences may then be detected. The instrument is provided with means for adjusting the lamp intensity and a meter for checking the lamp voltage. The microammeter can also be shunted to different sensitivities by a coarse and fine adjustment. The compensating network can be switched in or out as desired. The instrument case is fitted with extra terminals to accommodate a high-sensitivity galvanometer and other accessories, such as the manufacturer's transparency meter, gloss meter, colorimeter, and liquid comparator.

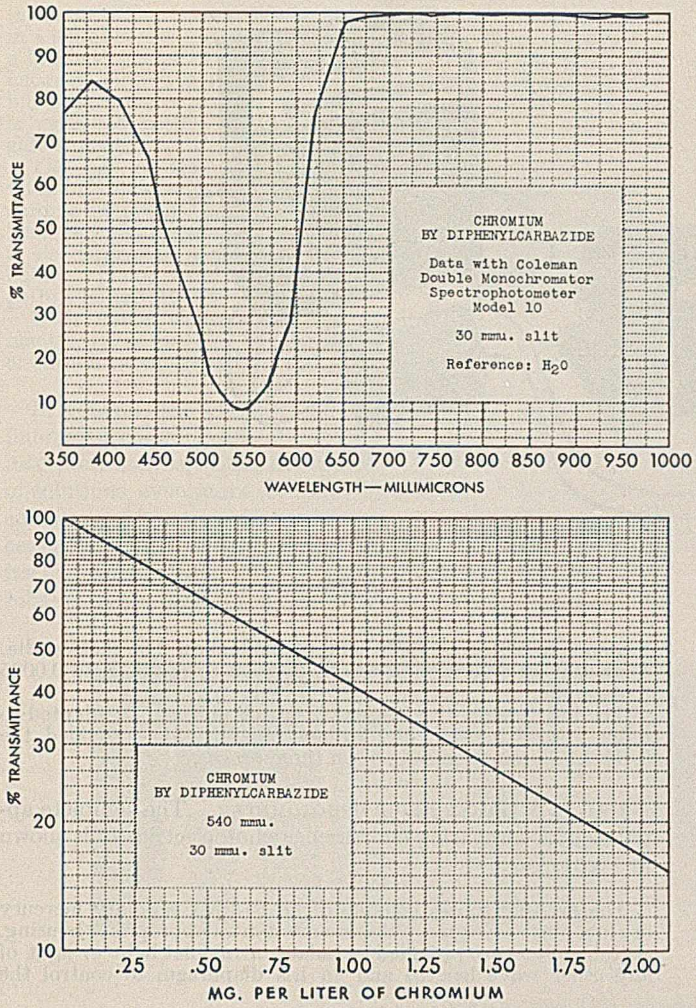
An instrument which was developed to meet the requirements set by the Institute of Paper Chemistry for the classification of book paper is shown in Figure 68. It involves the use of two vacuum photocells connected in series across a voltage supply. One cell receives light directly from the lamp through a variable diaphragm which is used as a compensator. The other cell receives light from the same lamp after it has been reflected from the unknown or standard sample and has passed through a mechanical diaphragm and a color filter. The diaphragm is so placed in the optical system that its transmission is directly proportional to its angular displacement.

If a sample to be measured is placed over the aperture in the instrument case it will reflect light into the measuring photocell. The mechanical diaphragm is then fully opened, in which position the dial indicates 1.00. The compensator dial is then adjusted until the drop in potential across each photocell is approximately equal. Since the common connection of the photocells leads to the grid of the amplifier tube, the resultant plate current will be about 400 to 500 microamperes. The sample is now replaced by the standard and the mechanical diaphragm is adjusted until the same value of plate current is obtained. Under these conditions, the measuring photocell is receiving the same amount of light as it did from the sample and the reading of the dial is a direct measure of the ratio of the reflecting power of the sample to the standard.



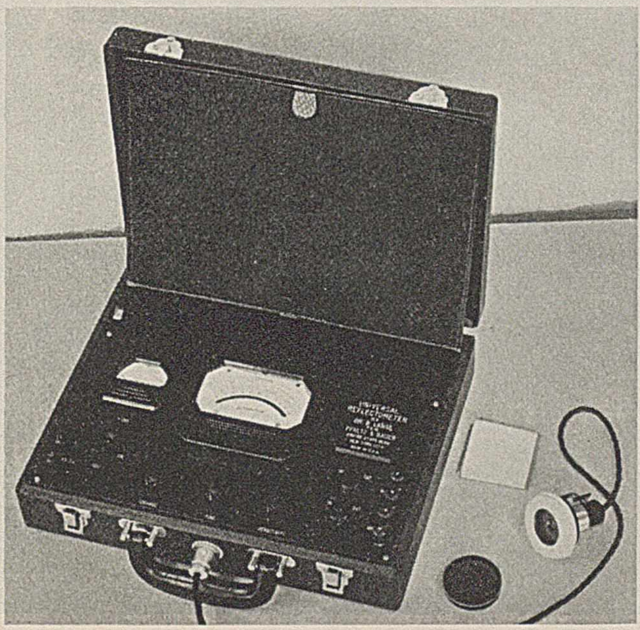
Courtesy, Coleman Electric Co.

FIGURE 65. DOUBLE MONOCHROMATOR SPECTROPHOTOMETER



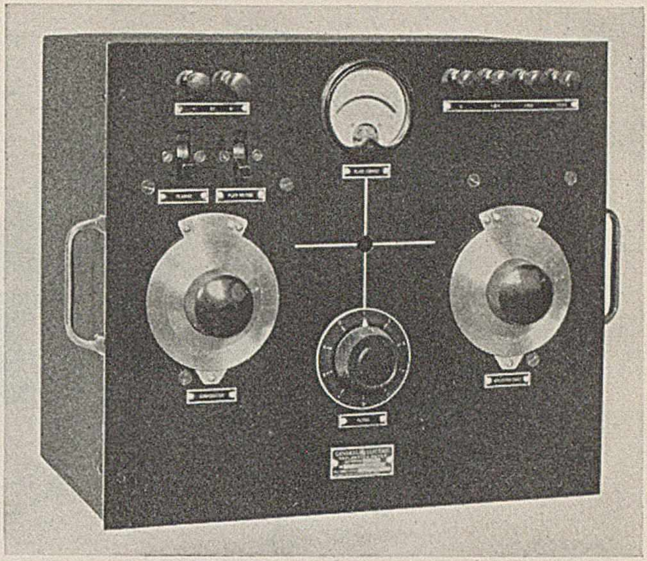
Courtesy, Coleman Electric Co.

FIGURE 66. REPRESENTATIVE RESULTS WITH PHOTOELECTRIC SPECTROPHOTOMETER



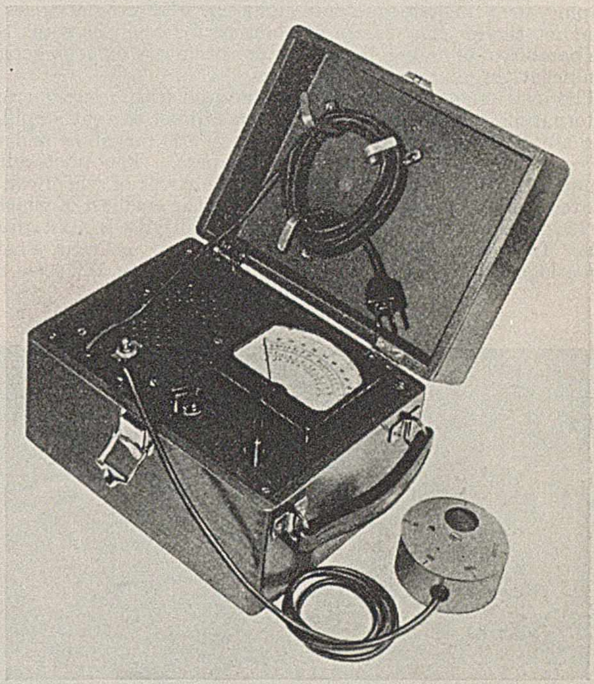
Courtesy, Pfaltz & Bauer, Inc.

FIGURE 67. UNIVERSAL REFLECTOMETER



Courtesy, General Electric Co.

FIGURE 68. REFLECTION METER



Courtesy, Photovolt Corp.

FIGURE 69. SMALL-SPOT PHOTOMETER

Nine selective color filters are employed to isolate different regions of the spectrum. They are mounted on a wheel and can be introduced in the optical path by rotating the center dial. With the aid of the vernier dial controlling the mechanical diaphragm it is possible to duplicate settings to 0.1 per cent on samples with a reflecting power of 50 per cent or greater.

ILLUMINOMETERS AND SPECIAL PHOTOMETERS. The pocket-size exposure meter is now well known and widely used. The same combination of barrier-layer cell and microammeter is available in many forms and for a large range of intensities. Giant search units, consisting of a number of elements connected in parallel, are used for measuring low levels of illumination.

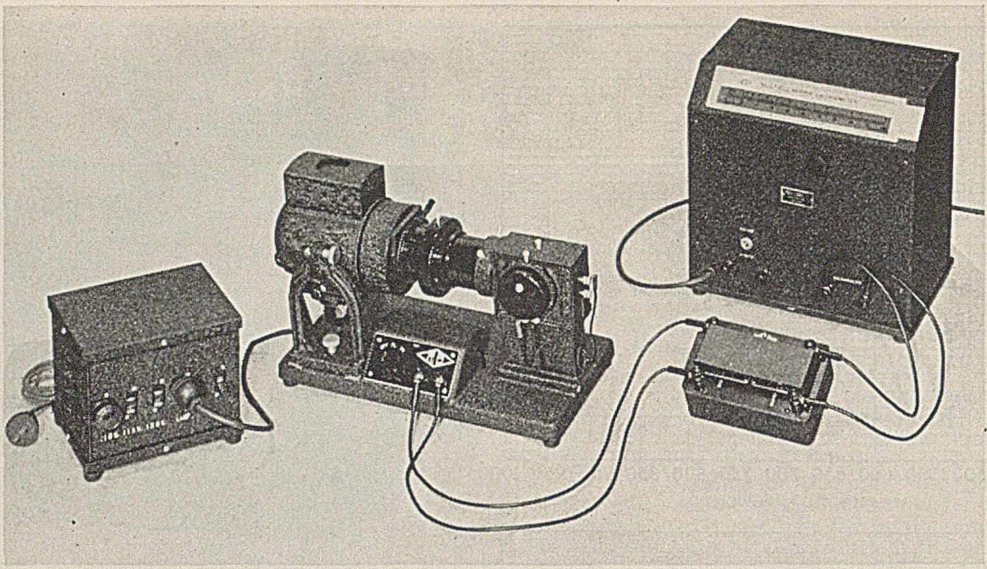


Figure 70. Fluorophotometer *Courtesy, Pfaltz & Bauer, Inc.*

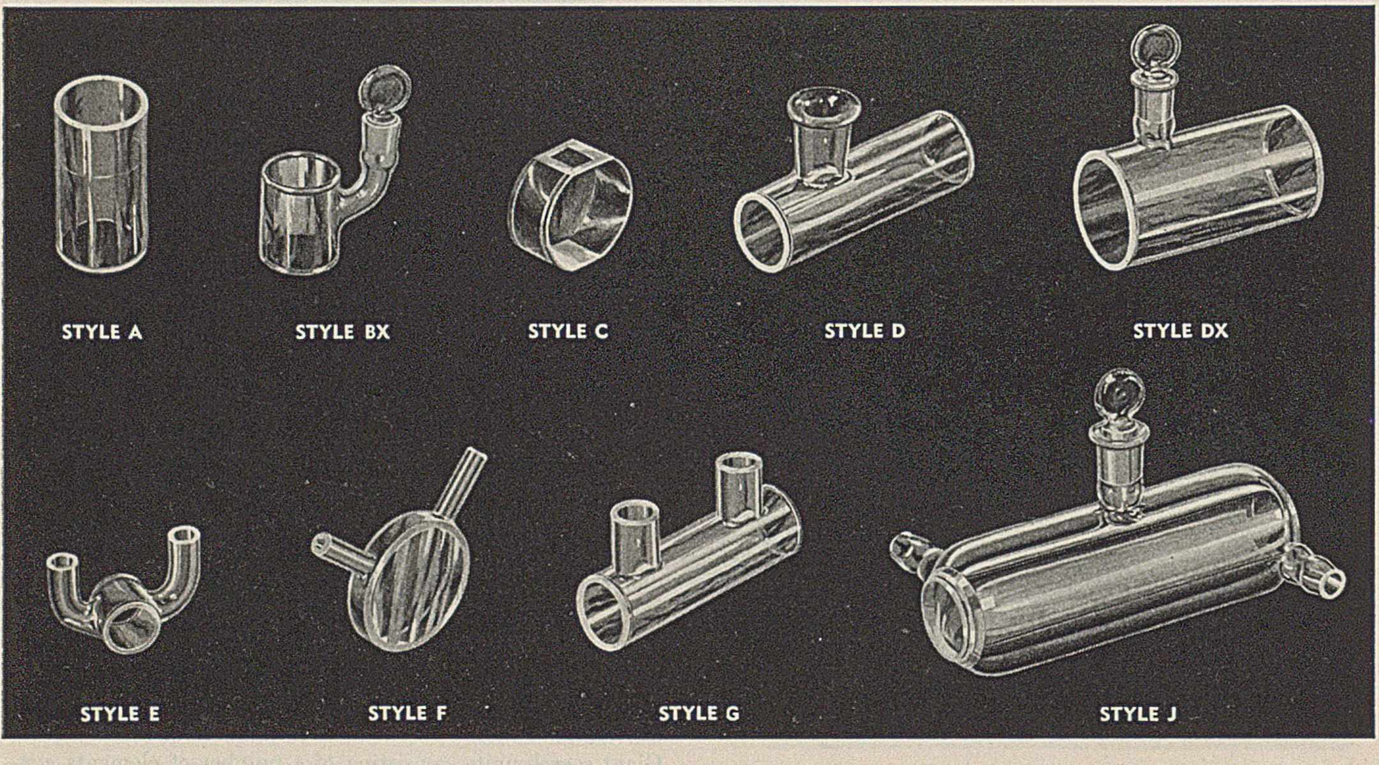
Another method for obtaining high sensitivity has been adopted in the small-spot photometer (Figure 69). It is a light-meter with phototube and electronic amplification. Its photographic uses include measurements on the ground glass of cameras, the focusing screen of photomicrographic cameras, and the baseboard of enlargers, and for densitometry on color separation negatives, and on spectrograms.

The instrument uses a vacuum photocell with a line-operated (alternating or direct current) stabilized direct current amplifier. The amplifier has an input impedance of 100 megohms and will measure currents as low as 10^{-9} ampere. The photocell is mounted in a cylindrical search unit, the cover of which can be rotated to expose four different apertures, the smallest of which is 0.02 inch in diameter. The amplifier sensitivity is also adjustable. Three scales are provided on the meter: a linear, a ratio, and a logarithmic scale. At the lowest sensitivity, full scale corresponds to 500 foot-candles and at the highest 0.05 foot-candle. With 100 scale divisions, a single division corresponds to 0.0005 foot-candle.

The instrument with its flexible search unit can be adapted to other optical instruments, without modification, provided the levels of illumination fall within these ranges.

Pfaltz & Bauer Fluorophotometer. The complete apparatus for measuring fluorescence photoelectrically is shown in Figure 70.

The exciting source consists of an 85-watt capillary mercury arc in a protective glass bulb, mounted in an appropriate housing. Suitable filters are provided to isolate ultraviolet light or light of any other wave lengths and an iris diaphragm to control the



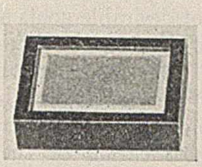
Courtesy, American Instrument Co.

Figure 71. Absorption Cells

intensity. The exciting light is absorbed by the solution contained in a suitable cell, and the fluorescent light is viewed laterally by a barrier-layer photocell. Additional filters may be interposed between solution and photocell to transmit the fluorescent light but absorb any scattered exciting radiation. The photocurrent is measured with a multiple-mirror galvanometer.

The use of this instrument for vitamin B_1 determinations by the thiochrome method has been described by Hennessy and Cerecedo (*17*). Its use is also suggested in the dairy, cereal, baking, pharmaceutical, yeast, and petroleum industries.

With minor changes, the instrument may be used as a colorimeter or turbidimeter.



Courtesy, Welch Scientific Co.

FIGURE 72. WOOD REPLICA GRATING

In general, the measurement of fluorescence is very difficult, and its interpretation, especially in the case of solutions, even more so. The fluorescence of solutions is a complicated function of temperature, viscosity, pH, electrolyte concentration, and concentration of the fluorescent material itself. No small part of the difficulty has been the lack of a reliable instrument for the measurement of fluorescence.

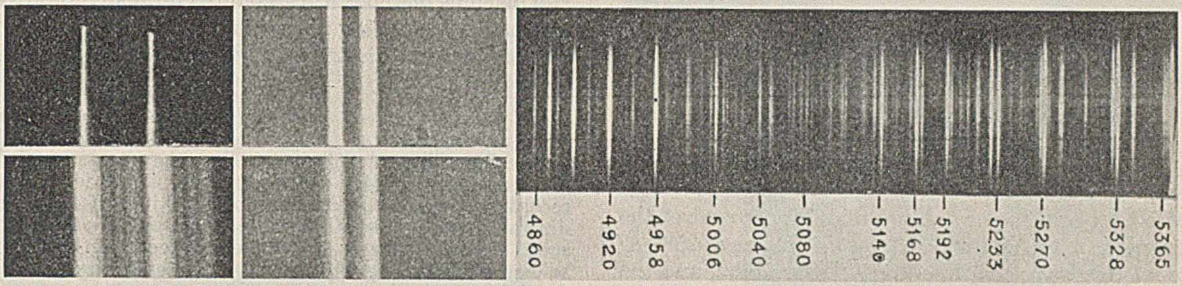
A good example is illustrated in the offering of the American Instrument Company (Figure 71). All windows are fused in place and are flat over the entire area to within 6 wave lengths. The cells are available in Pyrex bodies with either Pyrex or Corex "D" windows, and in fused quartz throughout. The cells are available in the styles shown, or styles meeting special requirements, in two tolerance classifications—standard and high precision within limits shown in the following table:

	Standard	High Precision
Flatness of windows (after fusing), wave lengths	6	6
Parallelism of liquid-glass interfaces, mm.	±0.025	±0.01
Parallelism of faces of each window, min.	±10	±10
Inside length (between faces of windows), % of nominal length	±1	...

Cells matched to 0.01 mm. and 1 per cent of nominal length, or cells made to nominal length ±0.005 mm. In both classes the actual mean length is marked on the cell to the nearest 0.001 mm.

Some progress has also been made in the fabrication of square test tubes with very creditable freedom from striations and other imperfections. They are machine-made, usually by shrinking cylindrical stock down on a mandrel of square cross section.

REPLICA GRATINGS. Film replicas stripped from a master grating have been used for many years as a cheap and convenient means for demonstrating the properties of the diffraction grating. Replicas are now finding increased use in commercially available instruments and this is due in part to the improvements which have been made in the preparation of the gratings.



Courtesy, W. M. Welch Mfg. Co.

FIGURE 73. COMPARATIVE SPECTROGRAMS TAKEN WITH REPLICA GRATINGS

ACCESSORIES FOR OPTICAL MEASUREMENTS. The contribution of Strong to these pages last year (*44*) should be an inspiration to future instrument designers, though this brief article contained but few of the valuable suggestions which are to be found in his recent monograph (*45*). Many of the advances which he discussed are rapidly finding their way into commercial production, affording the experimenter new materials and aids for his problems.

Most opticians can be induced to make special parts; some of the larger companies have gone farther and list a great variety of components. Thus in Catalog D-10 Bausch & Lomb describe lenses, prisms, and mirrors of glass and quartz covering practically all ordinary requirements. As an added convenience, several sets of optical parts are listed, which are very convenient for the research laboratory, shop, or development department. Attention is drawn particularly to the directions contained in this pamphlet for the correct method of listing specifications and tolerances for optical parts. The importance of this point is also discussed by Hardy and Perrin (*16*).

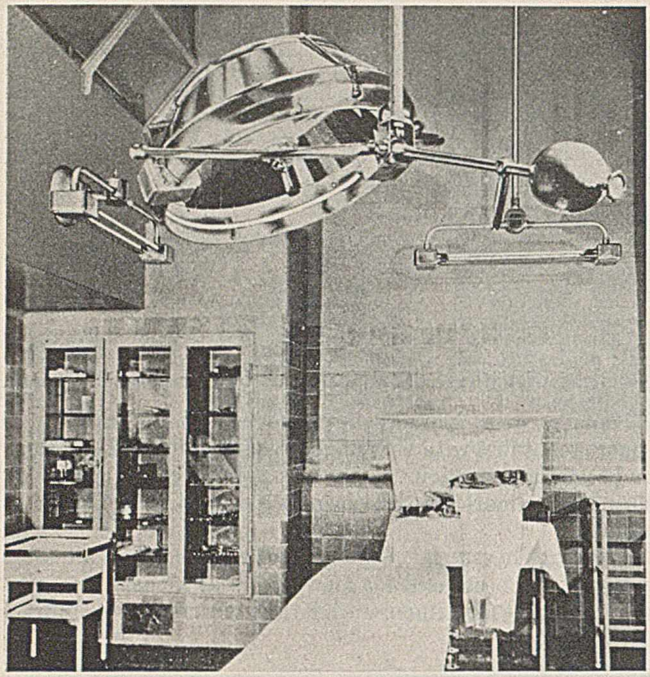
ABSORPTION CELLS. For many years American investigators have been handicapped by the dearth of good absorption cells. The foreign cells were very expensive, with a limited choice of styles, and were usually of the cemented type. While the cement was superior to any domestic attempts to duplicate it, it was not uncommon to have a cell fall apart during a measurement. The recent interest in photoelectric photometers and spectrophotometers has created sufficient demand to justify the manufacture of good cells.

The replicas first made by R. W. Wood of Johns Hopkins and manufactured with his advice and help by the Welch Company are illustrated by Figure 72.

Some idea of their improved performance may be gained by inspection of the spectrograms of Figure 73. The upper left was taken with a sodium arc source with Wood's 14,400 line Grade A replica. The one immediately below it was taken with the same setup but with a 15,000 Grade A commercial replica previously used in place of Wood's replica. The fuzzy *D* lines and "wings" are due to faults in the older replica. The middle set show the results obtained at half this dispersion, using Wood's 7220 Grade A replica and a 7500-line Grade A commercial replica. A wide slit was used in both cases; the relative exposures were 1 and 300 seconds, illustrating the great improvement in intensity. The right-hand spectrogram shows a portion of the iron bright-line spectrum taken with Wood's 4813 Grade B replica of only 0.5 inch square ruled area.

The replicas are available in Bakelite ring mountings or rectangular mounts as shown with ruled spaces ranging from 0.5 inch square to 100 × 150 mm. Grade A replicas will resolve the magnesium triplet having wave lengths of 5226.70, 5227.04, and 5227.36 Å. in the first order. This is very close to the theoretical resolving power of a grating of this size. The Grade B will resolve the doublet at 5267 Å. Rulings for both grades are either 14,440 or 4813 lines per inch. In the smaller sizes, these replicas are cheap enough to be bought by the dozen for individual classroom use. Even the advanced research size costs about the same as a good glass prism.

WESTINGHOUSE STERILAMP. These lamps are of the rare gas–mercury vapor type and operate on 30 to 50 milli-



Courtesy, Westinghouse Electric & Manufacturing Co.

FIGURE 74. STERILAMPS INSTALLED IN OPERATING ROOM

amperes at 275 to 475 volts, alternating current, depending on the length of the tube. The initial or starting voltages are about 50 per cent higher. More than 80 per cent of the radiant energy is in the first mercury resonance line at 2537 Å. Radiation at this wave length is highly bactericidal, and the principal use is in the field of sterilization in the food industry, in kitchens, dairies, restaurants, and hospitals. A typical installation in an operating room is shown in Figure 74. Some of the results achieved in these applications have been revolutionary, especially in meat storage, where, with the use of these lamps, much higher temperatures and humidities can be tolerated without spoilage and excessive dehydration and shrinkage.

Photochemists have used this general type of lamp for more than a decade, as a source of resonance radiation for studies in mercury-sensitized reactions. It has taken a long time to resurrect it from the laboratory and apply it to the practical problems of industry and commerce.

Glass and Glassware

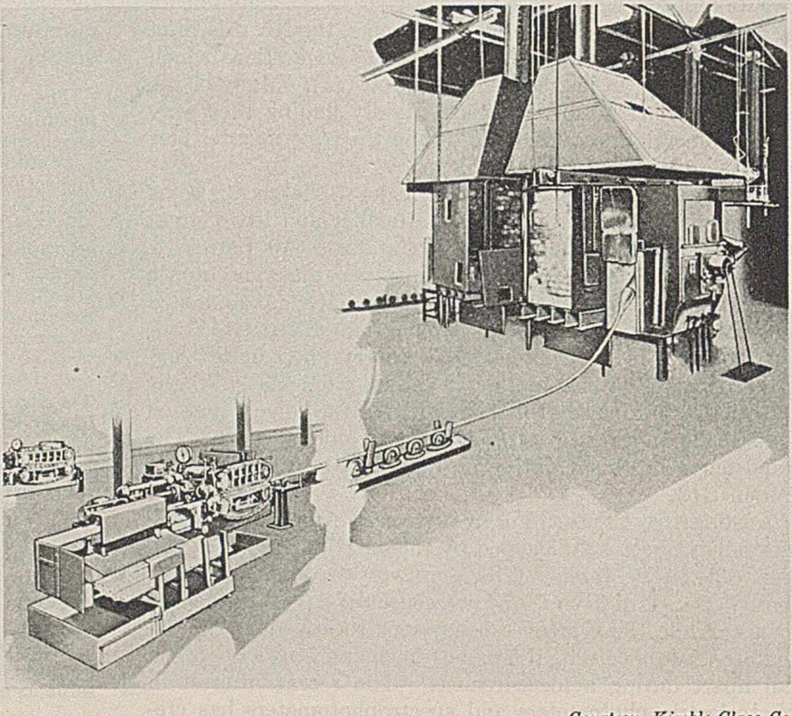
Glass has long been an indispensable material in the chemical laboratory. Many distinguished names have been associated with commonly used vessels and Erlenmeyer's, Kjeldahl's, and Soxhlet's are associated with objects more frequently than with individuals. The practice seems to continue; a catalog of pipets is practically a "Who's Who" in biochemistry.

The general advances in glass technology have been startling to scientists and laymen alike. One need but mention glass evening gowns, washable glass neckties, safety-rim cocktail glasses, glass building brick, shatterproof glass, and ornamental glass wall paneling. The advances in laboratory ware have been more subtle, with steady improvement, sharper tolerances, and the establishment of more rigid specifications of standards. Much of the credit for the high standards set by American manufacturers is due to the constant and untiring efforts of the Scientific Apparatus Makers of America and those committees of cooperating societies who set desirable goals and then proceeded to secure some degree of protection of native industry against foreign competition.

The glassware which was available before the first World War was largely imported. Aside from the small number of items which were obviously fit for Bureau of Standards certification or the foreign equivalent, the rest was best described as "junk", and could be sold only on a price basis. Size variations, poor annealing, obsolete design, and mislabeling or errors in calibration were very common. Most items were hand-made by cheap labor and illustrated the fact that the fabrication of glassware is an art and only occasionally a science. (It would be foolish to construe these statements as implying that a glass blower worthy of the name could not, if given the time and facilities, construct a piece of apparatus of almost any requirements and tolerances. We are concerned here with the large-scale production of comparatively simple items, such as beakers, flasks, pipets, burets, etc.) The American penchant for mass production and machine methods has accounted for many improvements. The task of designing the machine to perform a difficult operation, in itself, brings up problems which otherwise would seem trivial.

Let us consider one step in the fabrication of volumetric ware—machine-made tubing. A representative installation is shown in Figure 75. The carefully controlled ingredients are fed into a gas-fired furnace, the temperature of which is automatically recorded and controlled. A cone of skimmed molten glass is drawn off at the side of the furnace and pulled over rolls at high speed and an automatic cut-off deals 5-foot lengths of the tubing to a receiving tray. The speed of take-off and pour is carefully controlled to produce a uniform tube.

Such tubing never shows abrupt changes in dimensions; when changes do occur they are very gradual. An adjacent battery of machines grades the lengths of tubing into various diameters and another unit regrades these in turn according to weight.



Courtesy, Kimble Glass Co.

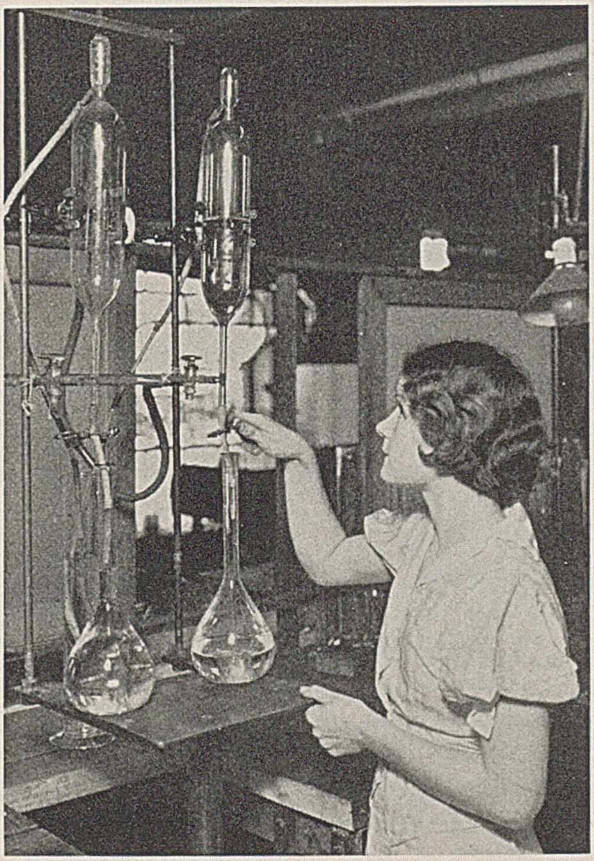
FIGURE 75. AUTOMATIC GLASS TUBE MACHINE

Articles which are made from such stock can be expected to show very little over-all variation in type size. As a starting material, machine-made tubing is characterized by uniformity of wall thickness, no appreciable changes in diameter, and straightness.

A very important characteristic of domestic equipment made by modern methods is the uniform care accorded each piece, regardless of the class into which it is to fall. Thus a buret, whether intended for an undergraduate, an industrial laboratory, or a research institute, is made under identical conditions and with the same materials. It is the care expended in calibration and the tolerances set which will determine the price. To the extent that one can utilize machines and automatic methods in large-scale production, there can be no great variation in quality. Thus in the case of burets where a manufacturer uses such methods the cheapest type will be as strong, free from defects, and reliable as the most expensive. One merely pays more or less, depending upon the effort which has been expended in individual calibration (Figure 76).

NINETY-SIX PER CENT SILICA GLASS. One of the most recent developments and one bound to have important applications in both laboratory and industry is the 96 per cent silica glass No. 790. The manufacture of this material requires methods which depart radically from conventional glass practice.

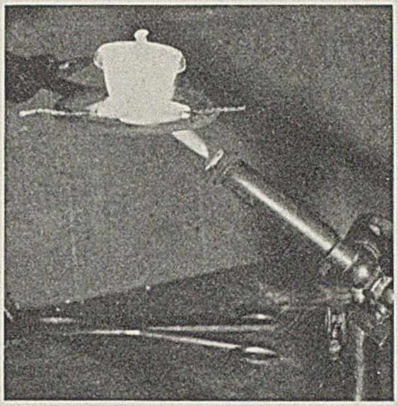
Normal glass is subject to leaching in hot solutions with the removal of practically all the constituents other than silica. The residue after being washed, dried slowly, and finally fired at carefully controlled high temperatures forms a transparent vitreous glass which is characterized by great chemical stability, high softening point, and very low thermal expansion. Another variety, No. 791, possesses very high ultraviolet transmission. A third variety, No. 792, is available for the preparation of massive, thick-walled articles.

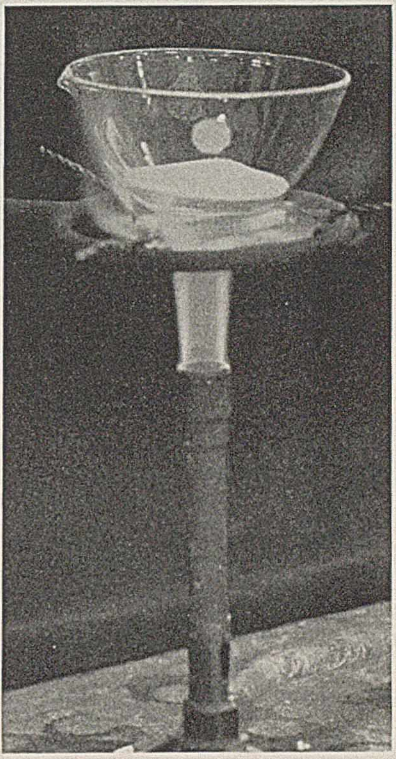


Courtesy, Kimble Glass Co.

FIGURE 76. CALIBRATION OF VOLUMETRIC WARE

Because of certain conditions imposed in the manufacture of this glassware and the need for oversized molds to allow for the shrinkage, there are at the present time definite restrictions in the matter of size, shape, and wall thickness. For the immediate future a limited number of items are commercially available, such as beakers, crucibles, flasks, and combustion and test tubes. Figure 77 illustrates the heat-resistant property of this material; an ordinary glass dish or crucible would not withstand these high temperatures. This line of ware is sold by Corning Glass Works under their Vycor trade-mark.

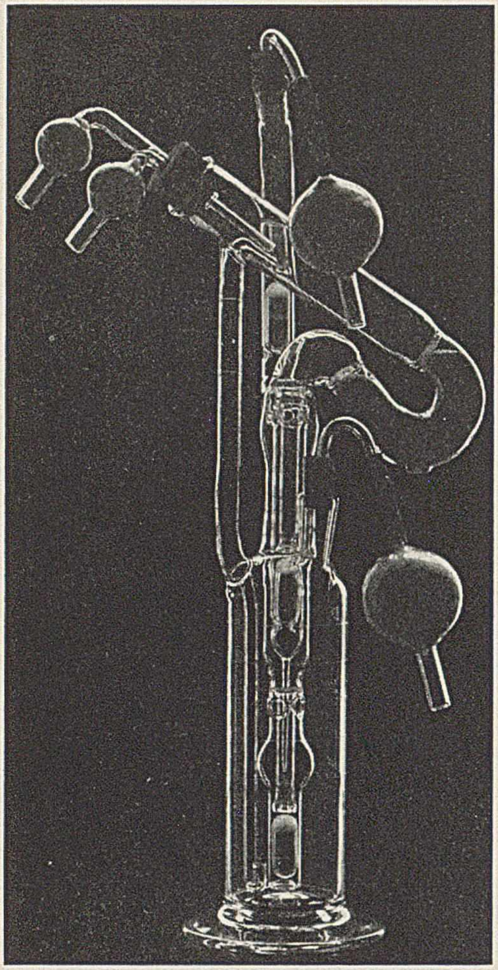




Courtesy, Corning Glass Works

FIGURE 77. VYCOR EVAPORATING DISH AND CRUCIBLE

STANDARD TAPER GROUND JOINTS. Continued progress has been made in the extended use of ground-glass joints of standard taper. Complete interchangeability is assured by checking with gages certified by the National Bureau of Standards. The Corning Glass Works has made numerous improvements in these joints aside from the interchangeability feature. These include heavy beads or lips at the end of the receiving joint, parallel external walls to facilitate holding by clamps, and the use of extra heavy walls in the interest of



Courtesy, Hopf Glass Apparatus Co.

FIGURE 78. CARREL-LINDBERGH PUMP

Among the countless examples of individual skill of which the investigator may avail himself we illustrate in Figures 78 and 79 the much publicized Carrel-Lindbergh pump and the electrophoresis apparatus of Tiselius.

An innovation promising utility as great as that of standard taper joints is the ball joint shown in Figure 80. Specifications for the commoner pieces of laboratory equipment can now include this useful type of connection. Another development by Ace Glass, Inc., illustrated in Figure 80, is a magnetically operated receiver in a still; provision can be made to operate this automatically according to a predetermined time schedule.

Figure 81 illustrates improvements in the standard boiling point apparatus with a unique provision for the periodic collection of a sample.

Automatic Recorders and Controllers

Following Behar (*2*) we may define an automatic controller as "an instrument which automatically controls, corrects, governs, or regulates (1) the processing, working, or storage condition or (2) the physical or chemical property of matter, or (3) the proportioning, to which it is applied".

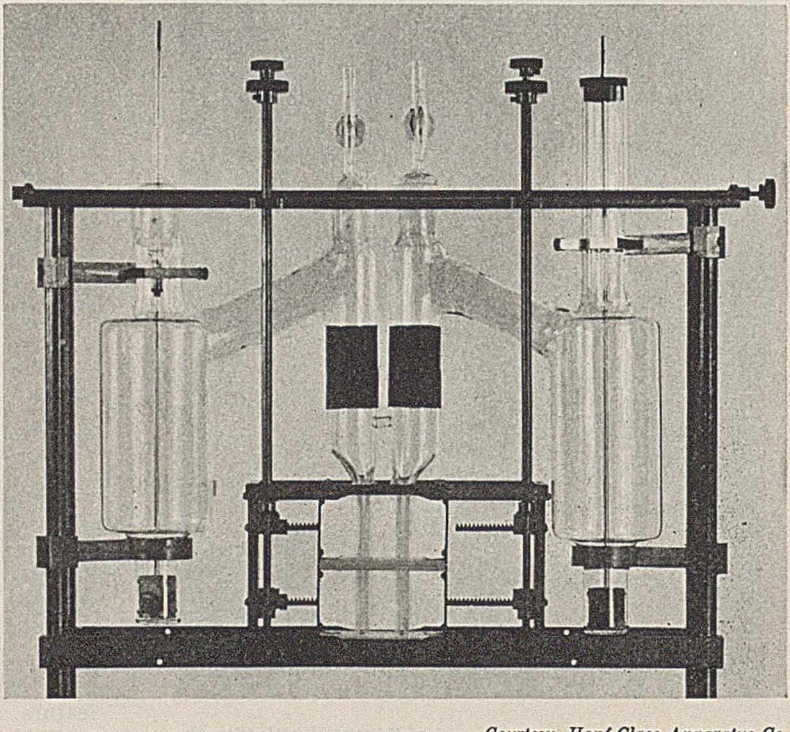
In keeping with the purpose of this review, no attempt will be made to cover this vast field, but rather, by isolated examples, to show the possibilities and potentialities of modern controllers. They are used so extensively and successfully in industry for performing countless tasks that they are often taken for granted as a small part of a completely mechanized process. The laboratory man in general is not too well acquainted with industrial controllers, for he often devises elaborate home-made contrivances, the commercial equivalents of which are already available and will perform more accurately, reliably, and economically. It is undoubtedly true that in automatic controllers of all classes one can obtain more for his money than in any other class of scientific instrument. This arises from the fact that controllers are used in industry in great and increasing number, and consequently their construction justifies elaborate tooling and an approximation to line-production methods. Alert instrument designers are aware of this advantage, and in many cases a new instrument, for a specific and limited application,

mechanical strength. Practically every conceivable glass setup is now available with standard taper joint fittings. The same developments have been extended to stopcock construction. There are corresponding improvements in strength, in minimization of freezing, and in improved vacuum-tightness.

CORNING ALKALI-RESISTANT GLASSWARE. This glass, specified as No. 728, was developed for use where resistance to alkalies is important.

It is substantially boron-free (0.06 per cent B_2O_3) and is therefore suitable for quantitative determinations of boron. The linear coefficient of expansion is 0.0000063 per degree Centigrade, between 0° and 350° C., and it is not recommended for general use under service conditions where high thermal resistance is required. Vessels made of this glassware are available in the form of beakers, bottles, condenser tubes, flasks, tubing, and test tubes.

GLASS BLOWING. The enriched resources of the glass industry and the products of the instrument industry, such as polarizers, temperature control lehrs, improved torches, and pressure gages, have all assisted the modern glass blower in his skilled calling. The average apparatus catalog gives ample illustration of the many special forms and patterns that can be obtained.

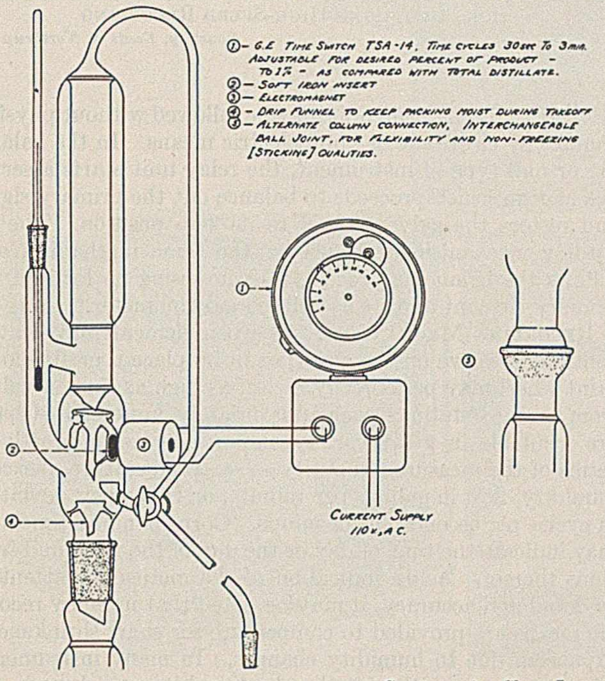


Courtesy, Hopf Glass Apparatus Co.

FIGURE 79. ELECTROPHORESIS CELL AND SUPPORT

is designed to be used in conjunction with a standard controller or recorder.

A satisfactory instrument must be rugged, require little or no attention other than periodic cleaning and inspection, be self-checking, and preferably be direct-reading in the desired quantity. In the latter connection, logarithmic or square law cams, etc., can be provided to furnish a linear indication or record. High sensitivity is always secondary to reliability and accuracy. A delicate laboratory instrument may be very sensitive, but may require constant supervision and attention. Its counterpart in an industrial recorder or controller is sensitive enough for the problem in hand but never at the sacrifice of stability. A false reading in the laboratory is annoying; in the plant it may be ruinous.



Courtesy, Ace Glass, Inc.

FIGURE 80. BALL JOINT AND MAGNETICALLY OPERATED STILL RECEIVER

Industrial instruments are built to indicate, record, or control a property or condition and may combine some or all of these functions. Thus in addition to simple indicators, we may have an indicator-recorder, an indicator-controller, or an instrument which performs all three functions—indicating, recording, and controlling. In addition to these primary functions, provision may be made for proportioning the control to the demand, for integrating or totalizing, for cycling or performing predetermined operations at definite times and proper sequence, and for telemetering.

PRIMARY ELEMENTS. The primary element may be a mechanically, electrically, optically, or electronically responsive device and its indications may likewise be translated to the recording or controlling mechanism by these agencies. The instrument may be used to measure, record, or control temperature, pressure, humidity, flow, liquid level, chemical or electrical conditions, or radiation (heat, visible or ultraviolet). Other conditions which can be converted to a proportional change in one of the above can be handled indirectly.

Among the mechanical elements are the Bourdon spring or helix which communicates with a tube and bulb. When used for temperature measurements the bulb may be filled with a gas, a liquid, or both, and three general classes are recognized. If a liquid-filled bulb is used as the temperature-sensitive element, the expansion or contraction of the liquid is transmitted through the connecting tube to the Bourdon spring or helix, the rotation of which (after lever or gear amplification) moves the pointer over the scale. Ambient temperature compensation is necessary and if the instrument case and connecting tube both have the same temperature, this is easily accomplished with a bimetallic system coupled in opposition to the helix. For long connecting tubes this will not suffice, and a duplicate helix and tube is used (without bulb) for zero setting and compensation. Scale readings are uniform in this type. In the vapor pressure type, helix and connecting tube are filled with liquid and the bulb contains liquid and its saturated vapor. This type requires no compensation for case or tube temperature. The scale is not uniform, since the relation between the vapor pressure of a liquid and its temperature is of the form

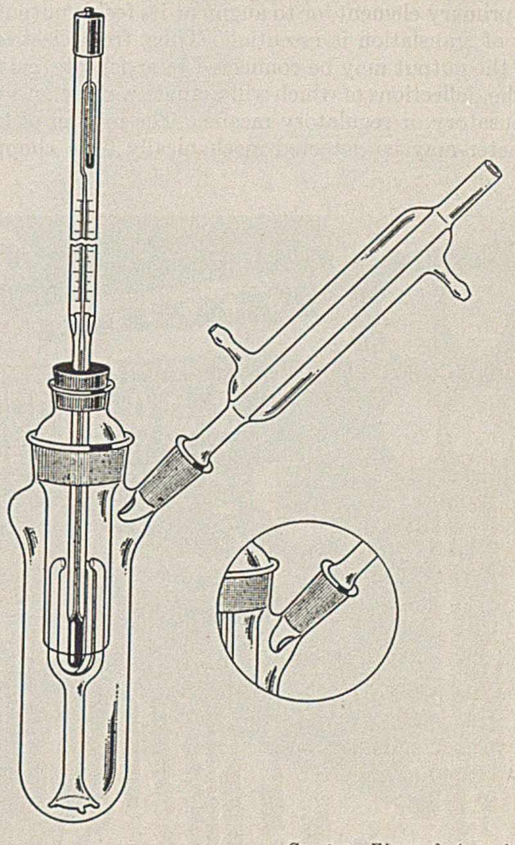
$$\log p = A/T + B$$

This has some advantages, since the open portion of the scale may be located at any desired point by appropriate choice of liquid. The third class is gas-filled, and will cover a wider range than the liquid or vapor pressure types. The scale is uniform and temperature compensation along the tube is usually made unnecessary by using a large bulb, the volume of which is great compared with that of the connecting tube.

Optical primary elements are single or multijunction thermopiles, bolometers, or photocells. In the case of photocells, the preamplifier, if one is used, may be considered part of the primary element.

Among the electrical primary elements are thermocouples, temperature- or pressure-sensitive resistance coils, and electrodes, the potentials of which are responsive to chemical conditions such as pH, or the oxidation-reduction potential of a system.

TRANSLATING OR RELAY MECHANISM. In some cases the response of the primary element may be sufficient to move a pointer directly or to actuate controlling mechanisms. More



Courtesy, Eimer & Amend

FIGURE 81. IMPROVEMENTS IN STANDARD BOILING POINT APPARATUS

Courtesy, Foxboro Co.

FIGURE 82. POTENTIOMETER CONTROLLER

Captions to illustrations, page 607

FIGURE 84. (*Lower right*) AIR-OPERATED RECORDING AND INDICATING CONTROLLER
Courtesy, Taylor Instrument Co.

FIGURE 85. (*Upper left*) ELECTRONIC TYPE OF CONTROLLER
Courtesy, Wheelco Instruments Co.

FIGURE 86. (*Center*) PHOTOELECTRIC HIGH-SPEED MULTIPLE-POINT RECORDER AND CONTROLLER
Courtesy, C. J. Tagliabue Manufacturing Co.

FIGURE 87. (*Lower left*) DETAILS OF RECORDER MECHANISM
Courtesy, C. J. Tagliabue Manufacturing Co.

FIGURE 88. (*Left center*) PHOTOELECTRIC INDICATING CONTROLLER
Courtesy, C. J. Tagliabue Manufacturing Co.

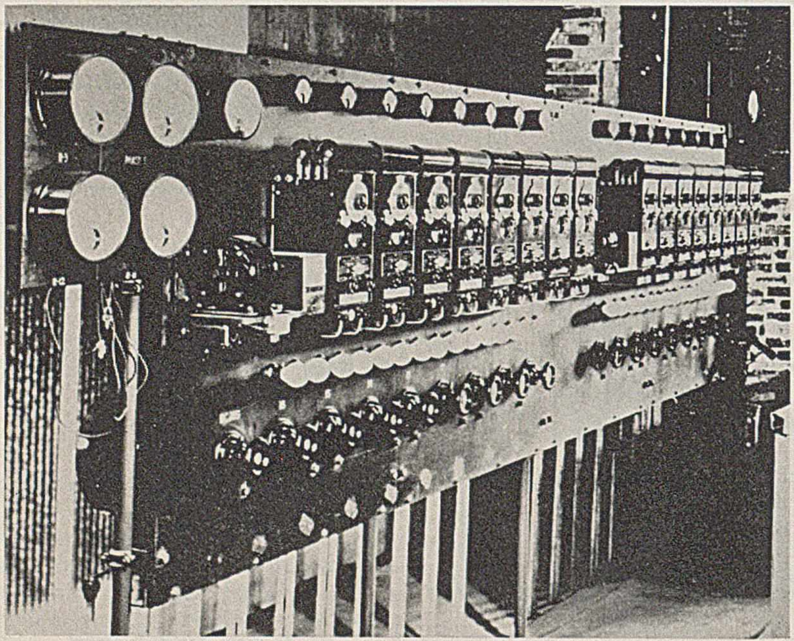
FIGURE 89. (*Upper right*) SPEEDOMAX RECORDER FOR APPLICATIONS REQUIRING HIGH-SPEED RECORDING
Courtesy, Leeds & Northrup Co.

frequently the effect is very minute and to avoid disturbance of the primary element, or to augment its feeble output, some means of translation is essential. Thus, from electrical elements the output may be connected to a delicate galvanometer, the deflections of which will actuate a relay and initiate compensatory or regulatory means. The motion of the galvanometer may be detected mechanically by a chopper-bar or "feeler" mechanism, or it may be followed without physical contact by electronic or photoelectric means. In the balancing or null type of instrument, the relay unit starts a servomechanism which proceeds to balance out the primary signal and restore the galvanometer to its zero position. The recording mechanism is driven by the same mechanism and follows the balancing process, thus imposing no load on the primary element and its associated galvanometer.

RECORDING MECHANISMS. The pen element may draw a continuous curve on the chart, or in its place a multicolored print wheel may periodically record as high as sixteen values from as many stations, each appropriately numbered. Charts are available in great variety and usually read directly in terms of the measured quantity—i. e., temperature, per cent humidity, flow in gallons per minute, or frequency deviation in cycles per second plus or minus. Corresponding time axes may indicate the time of day or the day of the week and fractions thereof. As an indication of the meticulous attention to detail and accuracy, it may be noted that in many recorders means are provided to compensate for chart shrinkage or expansion due to humidity changes. In many instruments, although the chart and its record are in full view, the indicating element is of bold dimensions in order that an operator or attendant may see the instantaneous value at considerable distances.

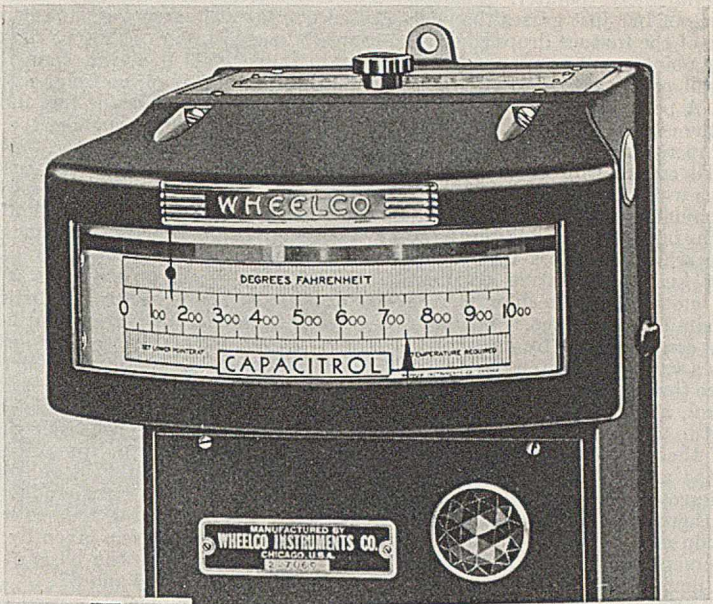
CONTROL MECHANISMS. The actual work to be done by the instrument in controlling a process is usually derived from some external source, and the primary element actuates pilot valves, relays, or contactors of one form or another. In an air-operated controller, the primary element controls a pilot valve which admits compressed air to a diaphragm motor or thrustor. A similar arrangement holds for hydraulic control. In electrically operated controllers, relay switches or solenoids are actuated which are capable of direct action or the starting of motorized valves. Alternatively the output of the primary element may be amplified or caused to excite thyratron tubes which supply the energy without any other intermediary.

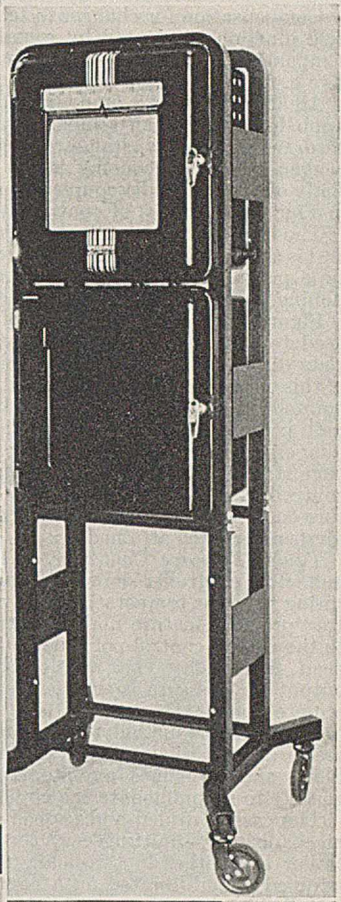
Foxboro Potentiometer Controller. This instrument, shown in Figure 82, will maintain the temperature of a furnace or oven at a value which is preset on the temperature dial. This setting selects a potential from a local source and opposes it to the potential developed by the thermocouple. A sensitive galva-

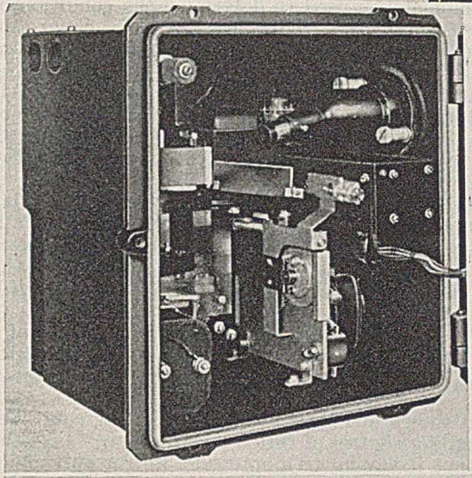


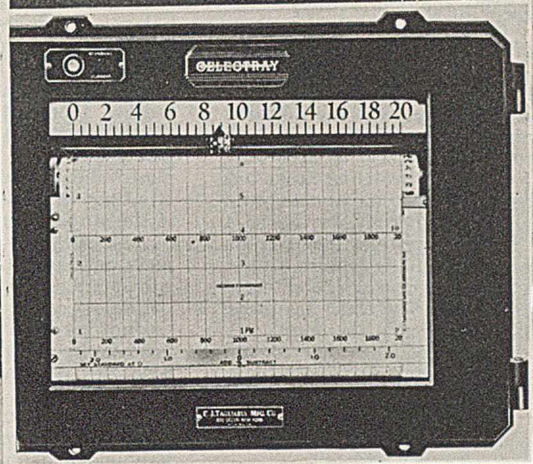
Courtesy, Foxboro Co. and Corning Glass Works

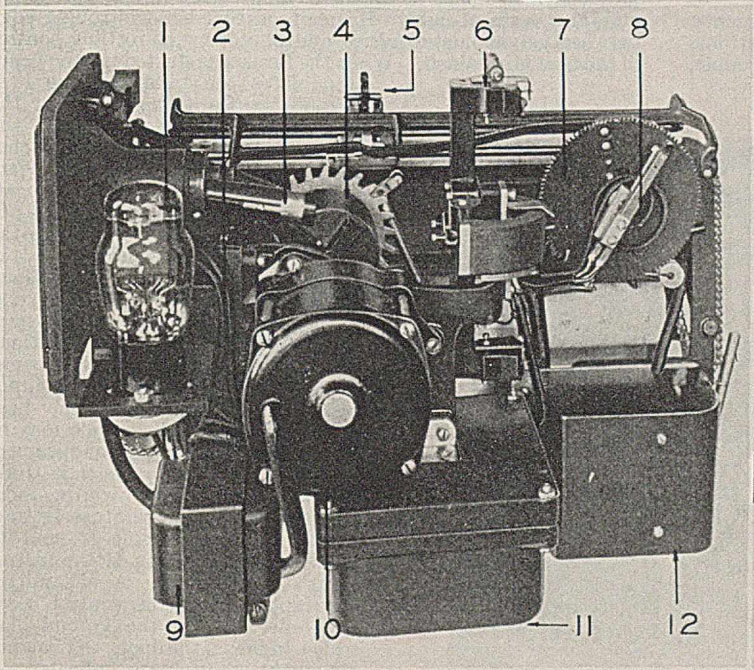
FIGURE 83. BANK OF POTENTIOMETER CONTROLLERS FOR ANNEALING GLASS

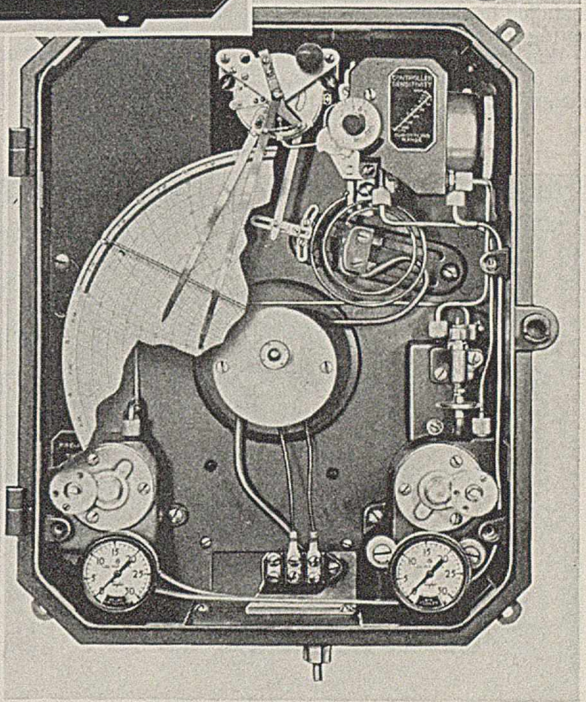












See captions, page 606.
Items described on pages 608 and 609.

nometer detects the difference in these potentials. A depressor bar periodically seeks out the galvanometer pointer. For the zero or balanced position the depressor bar just grazes the edge of the pointer. If the temperature of the furnace drops slightly, the deflection of the galvanometer pointer will now impede the depressor bar in its descent and will permit relays to close and supply more heat to the furnace. A pointer motion of 0.001 or 0.002 inch is sufficient to operate the controls.

Compensation for changes in temperature of the thermocouple cold-junction is effected by a small coil of wire having a high temperature coefficient of resistance which introduces the corrective e. m. f. in the potentiometer circuit.

All adjustments are made from the outside. In addition to the knob for the 12-inch temperature scale, there is a mechanical zero setting and a standardizing knob. A feature of great convenience and economy is the motor drive mechanism, the shaft of which can be coupled to similar controllers. As shown in Figure 83, groups of controllers can be driven by one motor.

The instrument is available with a variety of switch contactors and is also supplied in the resistance thermometer type. Another type provides for throttling control, and for operating proportioning valves. Units are also built to utilize air-operated valves.

Figure 83 illustrates a bank of these controllers which were used to control the furnaces in the annealing of the 200-inch glass disk for the Mt. Palomar telescope. From the description of this operation (*22*) we note that thermocouples at ten scattered points in the inner surface of the kiln measured the temperature, each being connected to a potentiometer controller. A constant temperature of 500° C. had to be maintained for 50 days to relieve stresses in the disk. By decreasing the dial settings of the controllers one after the other at 3-hour intervals, the temperature could be reduced at the rate of 1° C. in 30 hours until room temperature was attained.

Taylor Fulscope Controller. The air-operated recording and indicating controller shown in Figure 84 is typical of the Bourdon spring type for temperature and pressure recording and control. Its "pre-act" feature makes control-valve corrections according to the rate of control-point deviation. The throttling range has been increased. The relation between pen movement and output air pressure is sufficiently linear to permit its use as a remote pneumatic transmitter. The air system includes an improved relay air valve with precisely drilled sapphire orifice, metal disk auxiliary air filters to supplement a large external filter, and air gages mounted inside the case with neoprene gaskets to accommodate the circular apertures in the door.

The case is drilled and tapped to accommodate other control mechanisms, permitting easy conversion from one type of controller to another in the field. The actuating systems are assembled and calibrated on a new style of subbase which when installed in the instrument assures exact location of the Bourdon spring for accuracy of measurement.

Wheelco Capacitrol Controllers. This series of instruments, one of which is illustrated in Figure 85, is based on electronic means of control. A primary element, such as a thermocouple, is connected to an indicating millivoltmeter. The pointer of the millivoltmeter carries a very light aluminum vane. Motion of the pointer will carry the vane between two minute coils which are connected in an oscillating circuit. A motion of the vane of as little as 0.002 inch will change the inductance of the coils sufficiently to change the frequency of the oscillator and operate a relay, which controls the fuel input to the furnace being controlled. No contact is made in the primary control circuit; it is merely necessary for the vane to move within the plane of the coils. The desired control point is set by a knob at the top of the case, which moves an indicator over the lower portion of the scale and carries with it the oscillator coils. As soon as the millivoltmeter pointer carrying the vane finds these coils the control action ensues.

This system can be used with resistance thermometers and is suited in either class for proportioned control with a variable throttling range. A large signal lamp indicates when the heating cycle is on, and successful operation is visible at all times, since under these conditions the preset pointer and indicating pointer are in alignment on the scale.

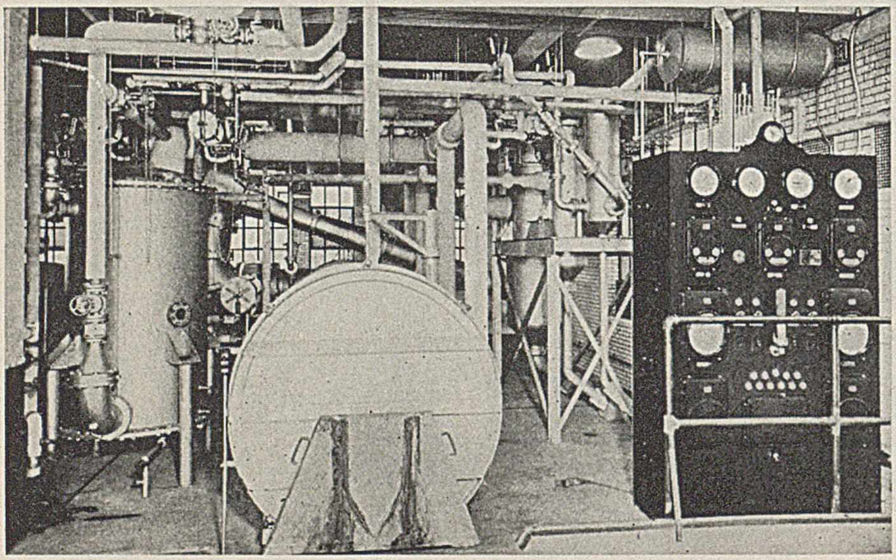
Tagliabue Recorders and Controllers. The balancing of a recording potentiometer by photoelectric rather than by mechanical means seems easy enough in principle, but its practical attainment involves several difficulties. The problem is one of stopping a moving light beam on the edge of a phototube without any tendency to "hunt" and to do so with speed and precision. An elegant solution has been given by Fairchild and Parsegian (*10*) and has been used as the basis of the Celectray recorders and controllers (Figures 86 and 87).

A mirror galvanometer is used to determine the condition of balance of the potentiometer or Wheatstone bridge. A beam of light reflected from the galvanometer mirror passes the "controlling edge" of a screen placed in front of the phototube. The amplified photocurrent operates relays which control a reversible motor. The motor drives the slide-wire contact of the bridge or potentiometer in the correct direction to reestablish balance. The exact value of the photocurrent is of no importance; the phototube is merely a control element to energize the relays. Hunting or oscillation is eliminated by introducing a time lag in the amplifier input, and for speed of response the back e. m. f. of the moving galvanometer is canceled artificially. Complete details of the circuit and the theoretical treatment of the galvanometer motion are given by Fairchild and Parsegian (*10*).

The speed of response with this arrangement is high: 20 seconds for a travel of 10 inches of the scale for an accuracy of a few hundredths per cent. At some sacrifice in accuracy (0.2 per cent) of balancing, the speed may be increased to 10 inches in 2 seconds.

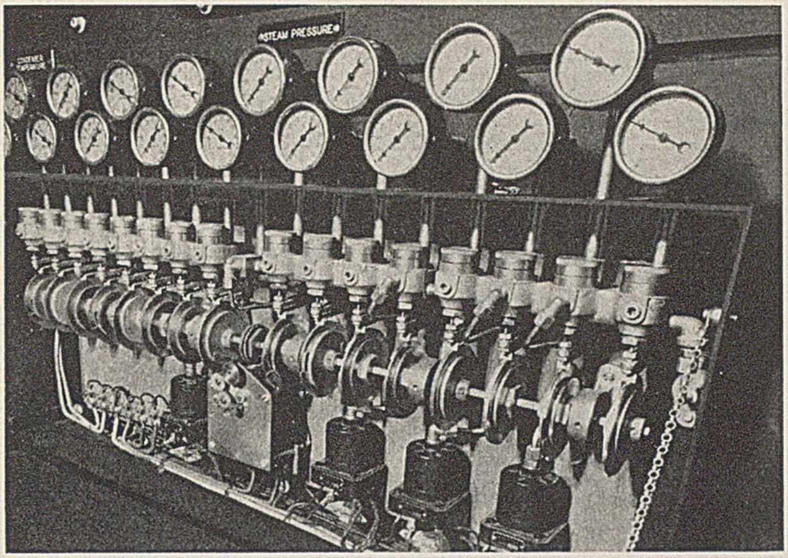
The instrument shown in Figure 88 is an indicating controller designed for throttling control of furnaces and ovens. Like the previous instrument it employs a phototube, mirror galvanometer, and beam of light. By reciprocating the controlling edge between galvanometer mirror and phototube, throttling control of the heat is obtained. When the furnace is started up, the beam illuminates the tube, because it is beyond the throttling zone and the heat is on for 100 per cent of the time. As the temperature approaches the preset value, the light beam enters the region of the reciprocating edge and is periodically cut off, and with it the heat supplied to the furnace. As it advances into the throttling zone the per cent of "time-off" increases. If it goes beyond this zone, the power to the furnace will be off 100 per cent of the time. Eventually the beam will assume a position at which the energy input to the furnace balances the heat losses. The throttling cycle may be 2, 12, 30, or 60 seconds, as specified, and the throttling range is fully adjustable from zero width, independent of the temperature setting.

An ingenious scheme is used to give visible indication of the instrument's performance. A 45° mirror intercepts part of the control beam and reflects it on the ground-glass scale window of the door. At balance a brilliant white line is indicated; if deflection occurs in the direction of higher temperatures a brilliant red line appears, at lower temperatures a green line. Two small



Courtesy, Bristol Co.

FIGURE 90. COORDINATED PROCESS CONTROL IN THE TOBACCO INDUSTRY



Courtesy, Bristol Co.

FIGURE 91. CYCLE-CONTROLLER FOR COORDINATED PROCESS CONTROL

color filters mounted on the ground glass, with an intervening clear space, furnish this very useful means of locating the prevailing trend at considerable distances.

Leeds & Northrup Speedomax. This instrument, a general view of which is given in Figure 89, is an automatically balancing direct current potentiometer which records full-scale changes in 1.5 seconds or less, with an accuracy and sensitivity which approach the readability of the chart. Over one hundred of these instruments are installed in steel mills for recording the temperature of hot billets as they pass through rolls; they have been used to record radio field strength speed, and to record temperature, pressure, and humidity measurements radioed from high altitudes (radio sonde). The use of the Speedomax in a microphotometer is discussed above.

Numerous papers have been published describing the Speedomax and its applications (*6, 50*). Briefly, it consists of a direct current potentiometer which measures the output of the primary element. An alternating current signal for the subsequent amplifier stage is derived from the unbalance direct current voltage by the action of a carbon-microphone modulator driven at constant amplitude at line frequency. The alternating current component, resulting from a direct current unbalance in the potentiometer, is amplified and with a push-pull transformer is applied to the grids of two thyratrons. The plates of the thyratrons are fed with an alternating current voltage which is in phase with the alternating current driving the modulator. Therefore, either one thyratron or the other will fire and drive the restoring motor in the correct direction, thereby rebalancing the potentiometer and moving the recorder pen proportionately.

In order to avoid overshooting, a tachometer is coupled to the motor shaft, and with the aid of a special circuit feeds back an opposing voltage in the potentiometer circuit, which is proportional to the square of the speed. In this way the speed of the restoring motor is controlled to maintain the sum of the tachometer, unknown, and potentiometer voltages equal to zero. Under these conditions the speed of rebalance is proportional to the remaining unbalance.

Chart speed can be either 4 inches per hour or 2 inches per minute. Phenomena of exceptionally short duration can be recorded with a wealth of detail which is very difficult or impossible by other means. One very important characteristic of the Speedomax is its ability to measure very small direct current voltages from low impedance sources. The difficulty of this problem is appreciated only by those who have had some experience with direct current amplifiers.

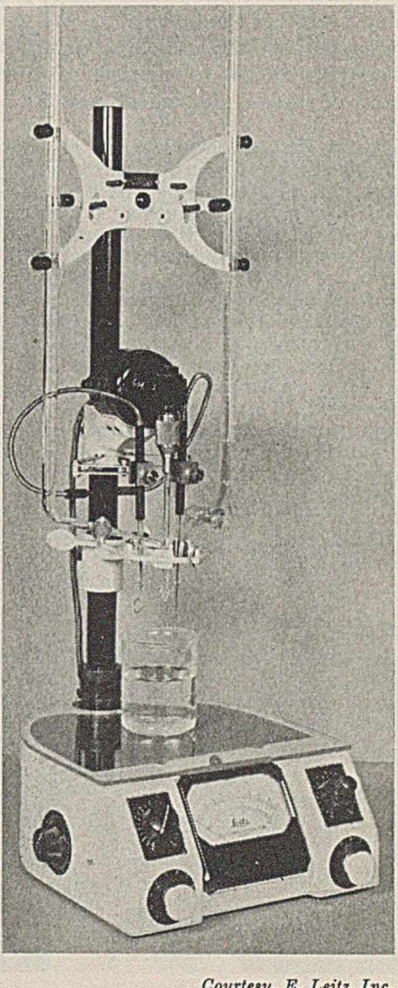
Bristol Coordinated Process Control. As an example of the application of industrial controllers to a complex series of operations, Figure 90 shows an installation of the Bristol Co. in a cigaret factory.

Partially dried tobacco is packed into hogsheads and aged for several years, during which the leaves dry out and become very material. This is usually done in large sweat rooms at a relative humidity of 95 per cent and a temperature of 100° F. About 2 weeks are required for each of the 1000-pound hogsheads to absorb 6 to 8 pounds of water. In the new process, controlled entirely automatically, the time is reduced to about 19 minutes and the tobacco contains from 30 to 60 pounds of water, with much more uniform penetration. It is achieved by alternate evacuation and steam admission to the large drums holding the tobacco. The sequence of operations is carried out with air-operated Bristol controllers. As many as 40 valves, ranging from 24 to 2 inches in size, are operated at least once and several of them as many as six times.

The cycle-controller shown in Figure 91 initiates each step at the correct time and according to a schedule which was found to yield the optimum performance. The camshaft is driven by a synchronous motor; each cam at the appropriate time trips a pilot valve which admits compressed air to a diaphragm motor valve. The appropriate gages give an indication of the position and prevailing condition in each valve. To control this process by hand would be humanly impossible. The coordinated control system automatically initiates each step and maintains pressure and vacuum at the intended values.

When it is considered that the average-sized cigaret factory may have as much as $1,000,000 worth of tobacco tied up at all times in the sweat rooms, the advantages of automatic control are apparent.

In this brief treatment, the author has left untouched many important points, such as the correct use of instruments in



Courtesy, E. Leitz, Inc.

FIGURE 92. ELECTROMETRIC TITRATION APPARATUS

process control. Some of these are embodied in the installations which he has illustrated. In general, an exact theoretical treatment of automatic control is lacking, and many prominent control engineers are of the opinion that instrumental developments are far ahead of application. When one is dealing with complex continuous processes, as distinguished from batch operation, there are process lags, surges, and upsets, which, to be properly accommodated by control instruments, require very careful study and calculation. Much ingenuity has been expended in devising throttling and anticipatory features for the instrument, but the intelligent choice and location of the controller are often very difficult. Notable progress has been reported in several papers on the subject (*14*, *26*, *27*, *28*).

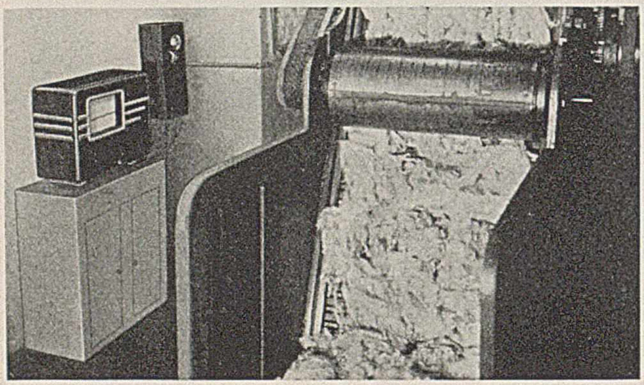
Instrumental Methods of Analysis

For many years the methods of physical chemistry have been utilized by analytical chemists. In recent times some of these methods have been extended to the completely automatic analysis of a given constituent including sampling, addition of reagent, automatic recording of the result, and initiation of alarms or appropriate corrective measures.

We shall discuss a few instrumental methods, some of them manual and others automatic.

Electrometric Titrations. Potentiometric titrations have been used for many years and form the basis of much of our knowledge concerning the nature of acid-base and oxidation-reduction reactions. As a practical means of routine analysis this technique has not found too general application, because of the complication in apparatus or the time-consuming nature of the operation. Within the past 2 years numerous compact assemblies of apparatus have appeared which simplify some of the manipulative requirements. One of the latest of these is shown in Figure 92.

The Leitz Electro-Titrator developed by Garman and Droz is characterized by compactness of assembly, the absence of trailing wires, and location of all necessary controls for the convenience of the operator. Distinctive features are the specially designed stirring motor, with silent reduction gear, which neither stalls nor hurls the solution out of the titrating vessel, a convenient spring clamp for holding the beaker, and adjustable electrode holder fitted with shielded plug-in connecting cables. The electron tube voltmeter with self-contained batteries is characterized by very high sensitivity and stability. The instrument will detect potential differences as small as 2×10^{-4} volt. The sensitivity is continuously adjustable by means of the control at the upper left of the panel. This control carries the main switch and a series multiplier for the meter. The input impedance is high enough to permit the use of glass electrodes, and indeed the instrument was designed primarily for this type of electrode. For ordinary oxidation-reduction titrations, platinum-tungsten and other bimetallic systems may be used. At the lowest sensitivity 1 inch of deflection corresponds to 200 millivolts and at the highest to 40 millivolts. For most of the commoner titrations the addition of one drop of reagent will cause nearly full-scale deflection. The high input impedance is best illustrated by the ease with which glass electrometric titrations may be made in nonaqueous media with this instrument.

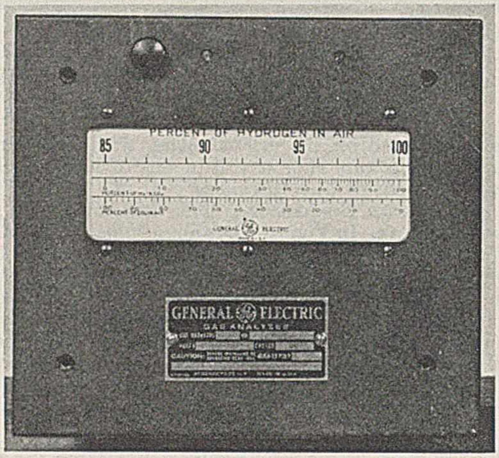


Courtesy, Wilkens-Anderson Co.

Figure 93. Glass Electrode Recorder

Glass Electrode Recorder. Since practically all modern glass electrode measurements are made with electron tube voltmeters, it is natural that the instruments are being extended to the use of automatic recording. Many companies have been studying this problem and have developed equipment for the purpose.

One of these installations is shown in Figure 93 in which the pH values are recorded on an ordinary 8.5 × 11 inch cross-section sheet. The recorder can be connected to the glass electrode system by means of a shielded cable. A motorized valve sampler and the electrode assembly are mounted close to the system under investigation and the time of sampling may be set for operating at successive intervals of 0.5 to 6 minutes. As with most recorder controllers, the system may be set to initiate appropriate corrective measures.



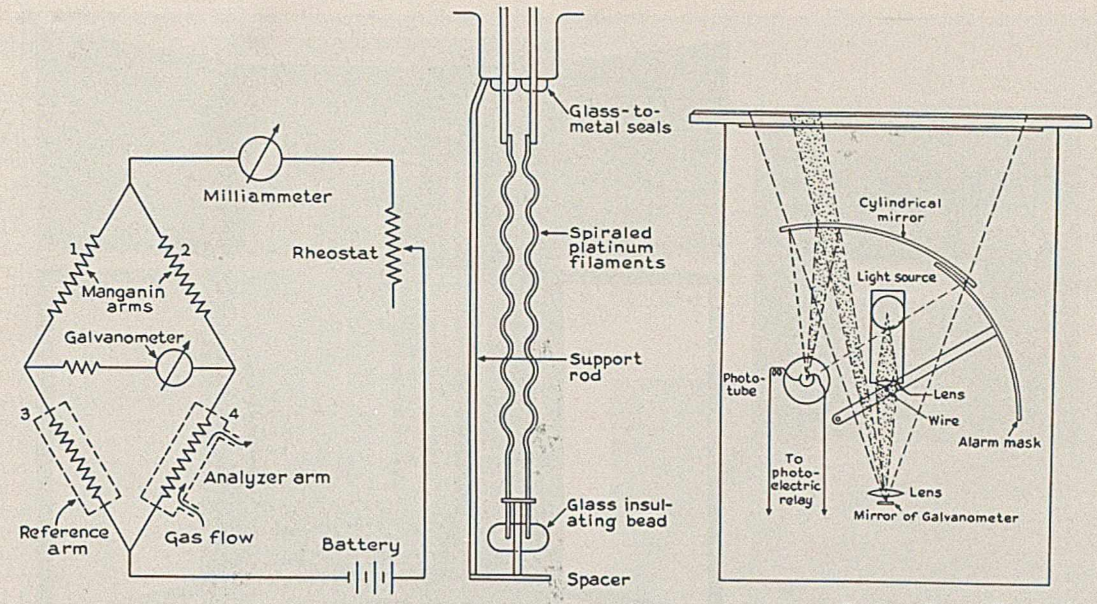
Courtesy, General Electric Co.

Figure 94. Hydrogen Gas Analyzer

Hydrogen Analysis Apparatus. Measurement of the thermal conductivity of gases for analytical purposes has been used for many years. The important monograph by Daynes (*9*) devotes some 350 pages to the theory, technique, and applications of these methods.

The chief reason for the design of the hydrogen analyzer shown in Figure 94 was the growing use of hydrogen for cooling large machinery. At the end of 1939 over 1,500,000 kilovolt-amperes of hydrogen-cooled generators were under construction by the General Electric Company at Schenectady. The first installation of this kind had been made only 2 years previously. In an installation of this type it is necessary to refill the casing with hydrogen after a shut-down for inspection or repairs. In doing this, it is customary to scavenge with carbon dioxide until the latter is present to the extent of about 70 per cent and then hydrogen is admitted until the percentage of hydrogen in carbon dioxide is about 97 per cent. When shut-down occurs and it is necessary to remove the hydrogen, the procedure is to admit carbon dioxide until the percentage of hydrogen in carbon dioxide is 10 per cent, after which air may be admitted. When properly carried out, these methods preclude the possibility of an explosive mixture in the casing and prevent unnecessary waste of gas. Obviously, an exact instrumental indication of the gas composition at each stage of the operation is necessary for satisfactory results.

The complete statement of this problem and its solution by means of this instrument have been discussed by Hansen



Courtesy, General Electric Co.

FIGURE 95.
(*Left*) BASIC CIRCUIT FOR GAS ANALYSIS BY THERMAL CONDUCTANCE METHOD
(*Center*) FILAMENT ASSEMBLY FOR GAS ANALYZER
(*Right*) INDICATING ALARM SYSTEM FOR GAS ANALYZER

TABLE III. RELATIVE VALUES OF THERMAL CONDUCTIVITY OF GASES AND VAPORS OF LIQUIDS AT 0° C.

(Values are an average obtained by different observers, and are related to air as unity.)

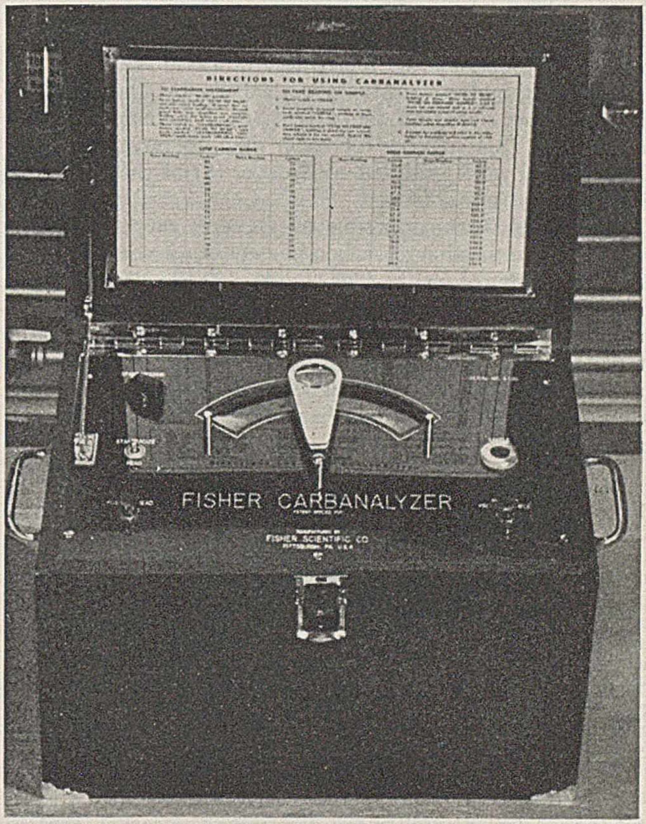
Gas or Vapor	Thermal Conductivity Relative to Air
Acetone	0.406
Air	1.00
Ammonia	0.907
Argon	0.685
Benzene	0.370
Carbon dioxide	0.590
Carbon disulfide	0.285
Carbon monoxide	0.959
Carbon tetrachloride	0.288 (at 100° C.)
Chlorine	0.323
Ethyl alcohol	0.708
Helium	5.93
Hydrogen	7.01
Hydrogen sulfide	0.648
Methyl alcohol	0.592
Neon	1.92
Nitrogen	0.999
Nitrous oxide	0.621
Oxygen	1.01
Sulfur dioxide	0.344

(*15*). We shall discuss a few points in this paper to make the operation of the instrument clear.

Figure 95 (left) shows the schematic diagram common to most thermal conductivity analyzers. The Wheatstone bridge will be balanced when the resistance of the analyzer arm is equal to that of the reference arm. At ordinary pressures the resistance of the analyzer arm will depend only on the composition of the gas surrounding it and on the ambient temperature of the casing. Since both casings are contiguous the latter requirement is met. Figure 95 (center) shows the construction of the filament assembly used in the gas analyzer.

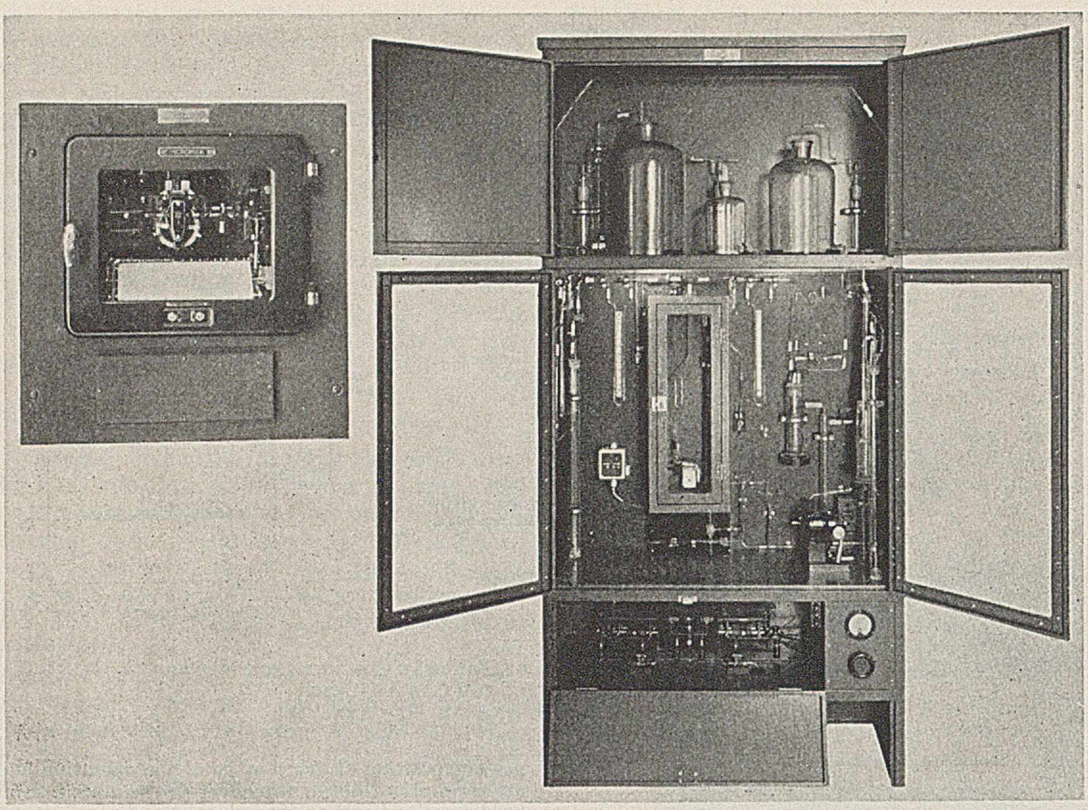
The distinctive feature of this instrument lies in the indicating and alarm system. Figure 95 (right) gives a schematic view of the indicating and alarm system. Deflections of the galvanometer are projected on the translucent scale which is calibrated empirically for (1) per cent hydrogen in air, (2) per cent hydrogen in carbon dioxide, and (3) per cent carbon dioxide in air. A portion of the galvanometer beam is intercepted by a cylindrical mirror, so that for any deflection that portion of the beam is reflected onto a phototube connected to an amplifier and relay. An adjustable alarm mask can be set to eclipse any portion or all of the cylindrical mirror. When this mask is set for a particular concentration limit, the excursion of the light beam beyond this point will actuate the photoelectric relay and sound an alarm. In this way the operator has a continuous visual indication of the gas composition at every stage of the operation and will receive an appropriate alarm whenever the composition deviates from predetermined and preset values.

This apparatus may be used in a similar manner for any mixture of gases in which the relative values of thermal con-



Courtesy, Fisher Scientific Co.

FIGURE 96. CARBANALYZER FOR DETERMINING CARBON IN IRON AND STEEL



Courtesy, Rubicon Co.

FIGURE 97. AUTOMATIC NITRIC OXIDE GAS ANALYZER

ductivity of the individual components differ sufficiently. Some of these values, which are given by Hansen in his paper, may be of interest to those who are not particularly familiar with the subject, and are reproduced in Table III.

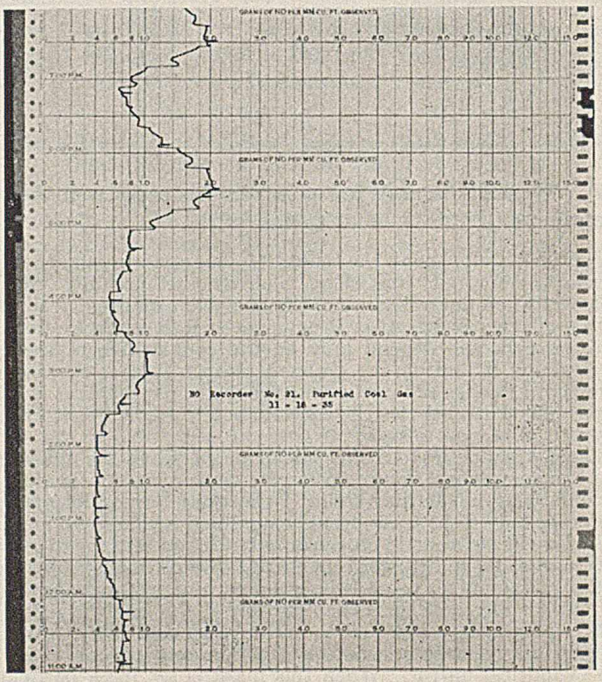
The design of apparatus for analysis by thermal conductance has occupied the attention of numerous manufacturers in this country for some time, following the very fundamental work initiated by Weaver (*9*) at the Bureau of Standards.

MAGNETIC DETERMINATION OF CARBON IN STEEL. The routine determination of carbon in steel is a necessary operation in every steel plant. The standard combustion methods have been subject to every known improvement and refinement, in order to obtain the necessary information in the minimal time. Some years ago it was found that under appropriate conditions, the magnetic properties of a chilled sample might be used as a reliable index of the carbon content.

One of these methods, developed by the research division of the Jones and Laughlin Steel Corporation, is embodied in the Fisher Carbanalyzer shown in Figure 96. In this instrument a sample of the melt, which has been poured and chilled in a special demountable mold, is introduced into a sample holder at the right of the instrument. After pressing a button several times, thus submitting the sample to a preliminary demagnetization cycle, another button may be pressed, yielding a deflection on the meter which is a measure of the magnetic permeability of the sample. Since the sample is of uniform size, this measurement may be correlated with the carbon content of the steel from a calibration curve which was originally prepared from samples, the carbon content of which was determined by standard chemical methods.

The importance of the method lies in the fact that with its aid the steel plant melter can determine the carbon content within ±0.02 per cent within 3 to 5 minutes. As is to be expected, special calibrations are required for some of the more complex alloy steels, but careful studies have shown that for a given class of alloy, unambiguous results for the carbon content may be obtained.

AUTOMATIC GAS ANALYSIS. We have already discussed the use of thermal conductivity in analyzing gas mixtures. An alternative approach to the problem is to submit the gas



Courtesy, Rubicon Co.

FIGURE 98. RECORDER CHART, NITRIC OXIDE RECORDER

mixture to appropriate chemical treatment and then subject the system to automatic optical analysis.

A very successful industrial installation of this type is shown in Figure 97. The concentration of nitric oxide in manufactured gas depends to a great extent upon operating conditions and, in general, is subject to wide and sudden fluctuations. It has been shown that extremely minute amounts of nitric oxide lead to gum formation, with a consequent danger of valve and orifice plugging. This recorder, built by the Rubicon Company, makes a complete analysis of the nitric oxide content of gas and registers the result on a moving chart. The record is directly in grams per million cubic feet of gas.

The apparatus consists of a chemical cabinet, where the metered and scrubbed gas is combined with a small amount of butylene that contains a definite percentage of the catalyst butadiene, after which a definite amount of commercial oxygen is admitted. After this operation the mixture is brought into intimate contact with a measured amount of Griess solution which reacts with the oxidized nitric oxide to form an azo dye. The solution assumes a characteristic color which varies from a light pink to a purple red, depending on the amount of nitric oxide originally present in the sample of gas. The light absorption is measured automatically by a differential photometer consisting of a constant-intensity light source and two Weston photronic cells. These cells are connected in opposition through a load resistor, and the net difference of potential due to the light absorption of the colored sample is fed to a standard Micromax recorder. The standard range of the recorder is 0 to 15 grams per million cubic feet of gas (Figure 98).

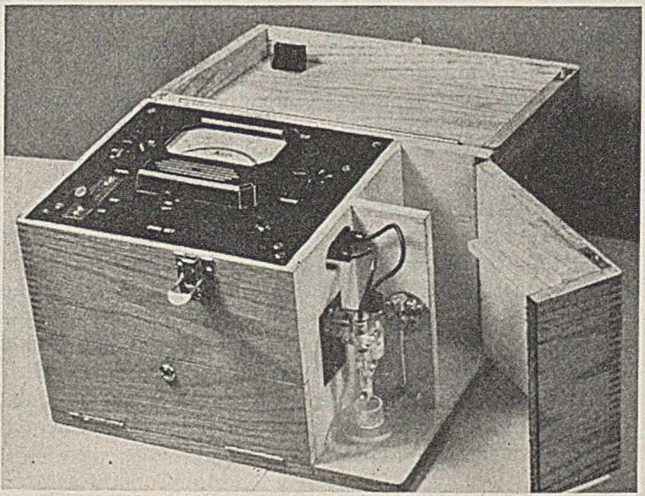
The capacity of the solution bottles (scrubbing and color reagent) is limited to one week of continuous operation. The oxygen and butylene cylinders need replacement once every 3 months. All solutions can be made up in any laboratory where a supply of distilled water free of nitrite is available. The cycling of all operations is entirely automatic and a continuous record of the analysis is apparent to the operator at all times. Periodic replenishment of the solutions as indicated above and inspection of the light source at 5-week intervals is the only attention required.

This is an excellent illustration of instrumentation applied to a standard and well-known method of chemical analysis. The importance of the determination and the economics involved justify the elaboration in equipment. In principle, the thousands of colorimetric methods which are known and used are entirely susceptible to the same treatment.

AUTOMATIC pH METER. Indicative of recent trends in the design of glass electrode equipment is the Leitz G. and D. automatic pH meter (Figure 99).

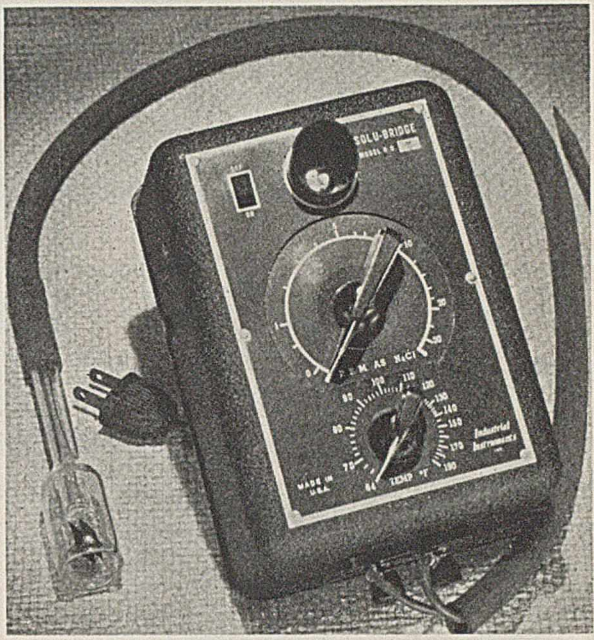
This instrument is based on the Poggendorf voltage compensation method, except that manual balancing has been eliminated. Potentiometric balance is secured electronically without the use of any moving parts. The instrument is calibrated against a single buffer, by one operation, after which the pH of any solution can be read directly on the meter. The meter has three scales: pH 1 to 6, pH 6 to 11, and 0 to 250 millivolts. The pH values can be read to 0.01 unit and are guaranteed to be accurate to ±0.05 pH unit. An ambient temperature compensator is provided.

This instrument combines the dependability of potentiometer-type instruments with the direct-reading advantages of electronic voltmeters and requires a smaller number of adjustments than either type. It may also serve as a 0- to 500-millivolt range voltmeter and as a direct-reading titrimeter for pH titrations. For the latter purpose it is supplied with a titrating stand similar to that used in the Leitz Electro-Titrator (Figure 92).



Courtesy, E. Leitz, Inc.

FIGURE 99. AUTOMATIC pH METER



Courtesy, Industrial Instruments, Inc.

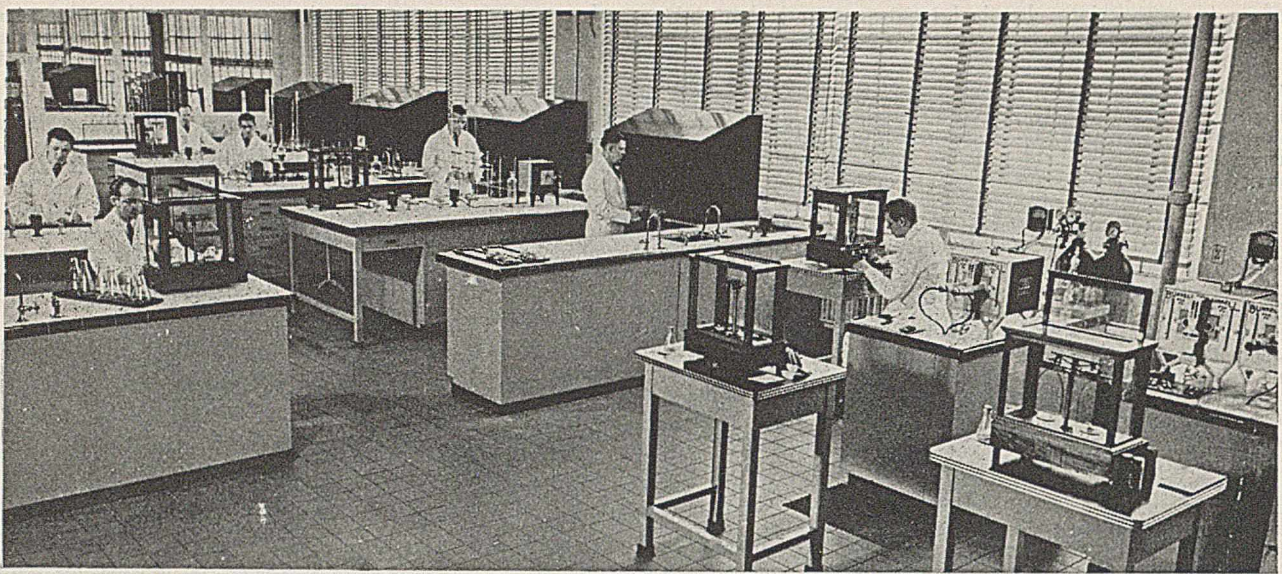
FIGURE 100. SOLU-BRIDGE, FOR ANALYSIS BY ELECTROLYTIC CONDUCTANCE

CONDUCTOMETRIC ANALYSIS. Chemical analysis by conductometric titrations has been practiced for more than half a century, but the tediousness of these measurements has in general excluded them from all but fundamental research studies. The empirical use of electrolytic conductance has its advantages, and in a few cases, notably in sugar ash analysis, has proved its worth.

In Figure 100 is shown a compact electronic conductivity bridge which may be used for measurements of this sort. In characteristic electronic fashion a "magic eye" tube is used as the bridge balance null-indicator. The bridge slide-wire is calibrated to read directly the concentration of a particular electrolyte in parts per million.

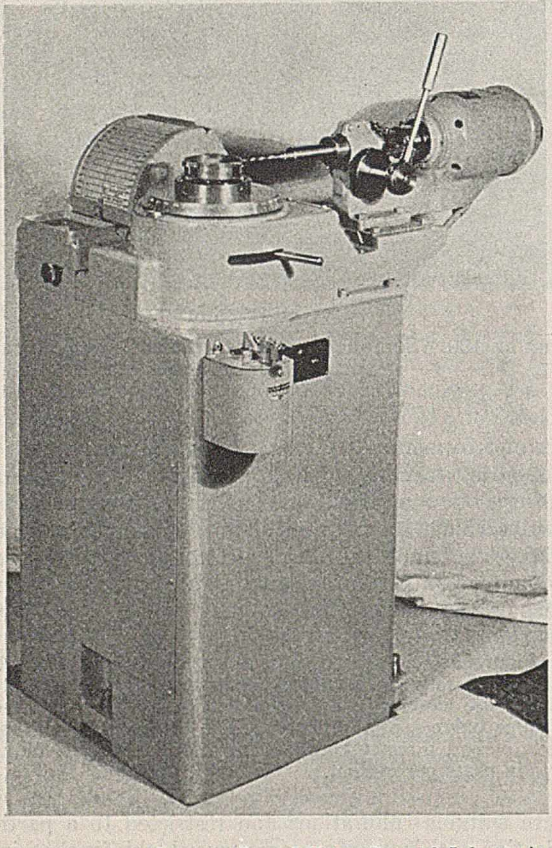
With suitable calibrations and restricted to a particular application, such instruments are very valuable for checking the purity of distilled water, steam condensate, rinse waters, etc.

It will probably be a long time before the full resources of instrumentation will be applied in the analytical laboratory. This is due in part to the understandable reluctance of analysts to accept a new method until they have sufficient assurance that deviation from the classical methods will produce wholly dependable results, even though it offers apparent advantages in speed and convenience. There are few industries that are quicker to apply the latest advances than the automotive industry. As an example of assiduous devotion to instrumentation we may mention the new research laboratories of



Courtesy, Chrysler Corp.

FIGURE 101. FERROUS RESEARCH LABORATORY



Courtesy, General Motors Research Laboratories

FIGURE 102. STATIC BALANCING MACHINE

the Chrysler Corporation. A view of its routine Ferrous Laboratory is shown in Figure 101, in which the entire surroundings are in keeping with the modern nature of the equipment used.

It is probably true that despite the great number of instruments to be found in modern analytical laboratories, the field of instrumental analysis is largely unexplored. Many of the methods that are used in physical chemistry still lack application in analysis, and in the author's opinion future developments must come from the instrumental side—that is, reduce existing research equipment to a convenient and practicable form for the use of the analyst. There is no serious lack of appreciation of these methods, but rather the realization that until they can be reduced to a rapid and convenient procedure, they must continue to remain primarily as research techniques. The field of electronic instruments promises to change this picture very soon and indeed we already have several illustrations in the case of glass electrode and electron tube voltmeters and photoelectric photometers.

$y = f(x)$—Coordinatographs

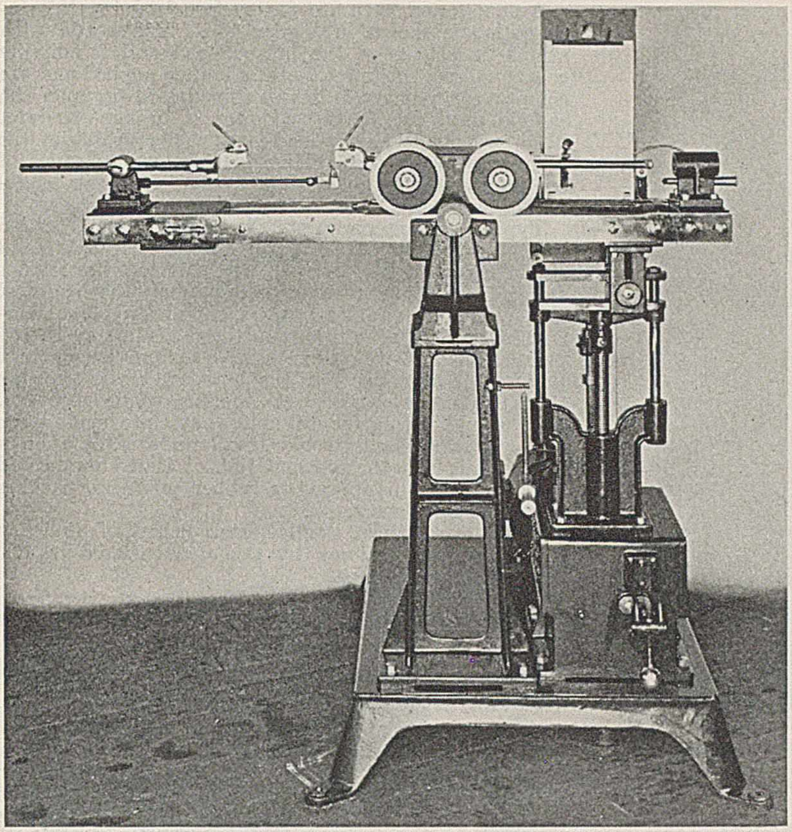
Following Behar's stimulating editorial (*3*) we use two expressions, the first having the telegraphic brevity of mathematics, the second a more restrictive, albeit awkward, connotation of any device which indicates or automatically records the mutual values of two variables, neither of which is time.

Many old and familiar instruments fall in this classification and the needs of industry create new demands. Very frequently the engineer, physicist, or chemist is required to develop some method for evaluating a property or condition which defies exact scientific definition. Avoiding for the moment such highly subjective qualities as taste and odor, we may mention hardness, comfort, wear, durability, useful life, etc. A little study often suggests two variables, the functional relationship of which should give the desired information, and if these variables are simple enough and measurable, we have the basis of a useful instrument. Mathematical exactness is usually lost somewhere in the journey, inasmuch as the "function" is rarely reducible to fundamental concepts.

The importance of such devices is evident. With an acceptable and reproducible criterion available, the chemist can study the effect of composition, impurities, and details of procedure with greater assurance of success.

We may start this discussion with a device which, although it is primarily a tool and seemingly involves the element of time, may be used as a criterion of homogeneity.

The static balancing machine shown in Figure 102 is designed to balance disks, flywheels, and other similar parts where the unbalance is in only one plane. The part to be balanced is suspended and spun by a motor. The shaft is located by three



Courtesy, Henry L. Scott Co.

FIGURE 103. INCLINED PLANE TESTING MACHINE

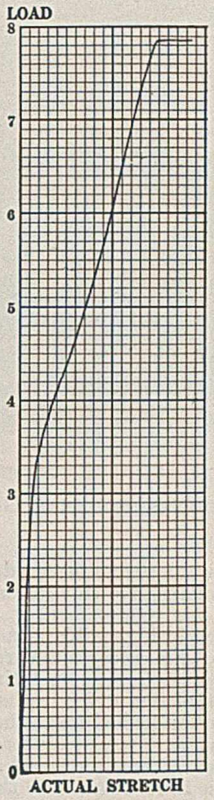
pivoted rollers, spring-loaded. When the shaft with test specimen is out of balance, it will run off center and cause the roller arms to oscillate. The roller-arm motion is transmitted by levers to a small tilting mirror. The motion of this mirror is observed by reflecting a beam of light from its surface on to a polygonal rotating mirror and thence to the translucent screen (upper left). Oscillation of the primary mirror causes a spot of light to move in a horizontal direction on the screen. The rotating mirror causes the spot of light to move in a vertical direction on the screen and in phase with the rotation of the shaft. The resultant trace for the unbalanced condition is a sine-wave; for perfect balance a vertical line appears on the screen. The screen is calibrated so that the peak of the wave shows the angular position of the unbalance. The amplitude of the sine-wave measures the amount of unbalance in ounce-inches. It may also be calibrated to yield directly the appropriate drill depth for correcting the unbalanced condition.

This machine is indispensable for the adjustment of rotating parts in fine machines and instruments. It is evident that in tests made on perfectly symmetric and geometrically balanced specimens, any observed unbalance will be a measure of inhomogeneity.

INCLINED PLANE TESTING MACHINE. The practical utilization of most materials requires definite knowledge of such characteristics as tensile strength, stretch, hysteresis, or fatigue. In one case the sample may be a rayon fiber or a microscopic wire, in another case it may be a steel girder. The correlation of this information with chemical composition or treatment and with the physical changes to which the material has been subjected is the basis of much of modern industrial research. The performance of these tests is usually automatic in order to eliminate personal variations and to assure reproducibility.

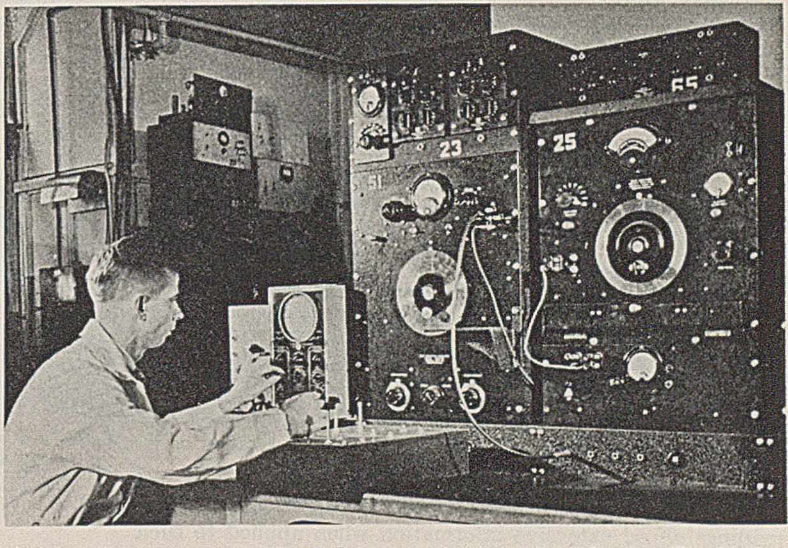
As a typical example of this class of instrument we may discuss the Scott testing machine shown in Figure 103. This instrument is characterized by a constant rate of specimen loading—that is, it applies a definite unit of load per unit of time to the sample—and can be made to relieve the load at the same rate. The sample is mounted between appropriately fashioned clamps, one at the fixed clamp on the left, the other in the clamp attached to the freely rolling carriage. The hardened and polished stainless steel plane on which the carriage is free to roll is tilted in clockwise manner and at a definite rate by the motor-driven mechanism shown on the right.

The stylus, an ordinary ink pencil, is mounted on the carriage and rests lightly against the chart. When the specimen breaks, the stylus is automatically lifted from the chart and replaced when the machine is returned to the starting point. With the chart-platen fixed, the record will be on angular ordinates. If the platen is moved uniformly in a vertical direction, the record will be drawn on rectangular coordinates. Frictional losses are entirely negligible for the loads in question, since the wheels are mounted in precision ball bearings. For models covering much



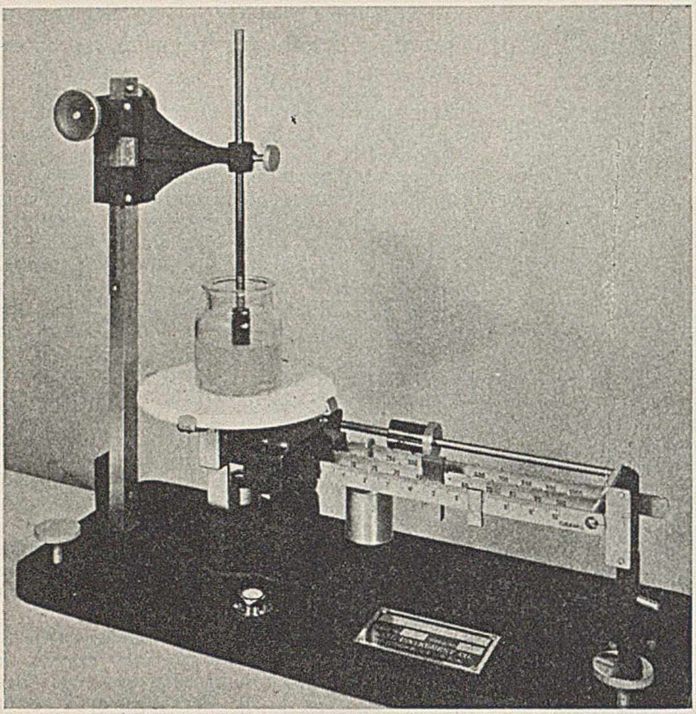
Courtesy, Henry L. Scott Co.

FIGURE 104. TENSILE STRENGTH ELONGATION TEST OF RAYON



Courtesy, Chrysler Corp

FIGURE 105. ANALYSIS OF SYNTHESIZED VIBRATIONS



Courtesy, Saxl Instrument Co.

FIGURE 106. COMPRESSOMETER OR GELOMETER

lighter loadings, sapphire jewel bearings are used, again reducing losses from this source to a negligible fraction of the prevailing load.

A typical example is shown in Figure 104 of a tensile strength elongation test of rayon. This autographic record reveals a maximum tensile strength of 7.85 with an ultimate stretch of 14.5 per cent. The yield point lies at 3.2 in the load direction. In this example, the sample was loaded up to the rupture point. Additional information may be obtained by loading up to any desired fraction of the maximum tensile strength, then deloading uniformly. The return trace in its relation to the original trace will supply information on hysteresis and fatigue.

A great variety of materials may be profitably studied by these instruments—rubber, textiles, plastics, wires and cables, and, unhappily, parachute shrouds.

"COMFORT" FROM A CATHODE RAY TUBE. The sources of vibration in a motor vehicle can be studied individually and corrective means can be devised to minimize them. The residual effects which are contributed by the motor, uneven road, cross winds, and tire distortion resiliencies are all blended into a very complex pattern made up of the various vibration frequencies with their corresponding amplitudes.

The instrument assembly shown in Figure 105 enables Chrysler research engineers to synthesize any resultant pattern of this sort. From the large signal generators in the background groups of frequencies may be selected at any desired amplitude, fed into a mixing network, and then applied to the vertical deflector plates of the cathode ray oscillograph. The horizontal plates supply a convenient time base. The resultant pattern appears on the oscillograph screen and portrays the composite result of all the individual disturbances. In this manner the importance of the individual components may be studied over a wide range of conditions and with a great saving of time. This installation is useful for fundamental synthetic studies of complex vibrations and is not to be confused with the much simpler portable devices or "rideometers" which give a general indication of riding comfort in a test car. These are usually of the accelerometer or vibrometer type.

COMPRESSOMETER OR GELOMETER. Load *vs.* compression readings afford extensive information when applied to such materials as gelatin, glue, staple fiber, folded fabrics, rolled cloth, rubber products, paper pulp, and many others.

A simple and accurate means for obtaining this information is shown in Figure 106. The bottle with sample is placed on the balance pan and is suitably counterpoised. A known weight is then applied and the compression plunger is gently forced into or upon the sample until the balance pointer is brought to zero. More weight is now added and a new value of the plunger is found. Successive settings give a series of compression-load values. The system may now be deloaded progressively.

Typical characteristics are shown in Figure 107 taken with a recently developed synthetic wool (left) and staple rayon (right). It can be seen that the regular staple fiber depresses immediately upon the slightest load, after which a linear load *vs.* compression characteristic results. On returning in the deloading cycle, the parallel relation, which exists in the improved material (left), does not appear in the standard fiber, showing that this material possesses inferior elastic recovery. This would mean, for example, that cloth made from this standard staple would crush more easily than a fabric made from the new material. Related data would be very useful in appraising rubber products, packing materials, upholstery, etc.

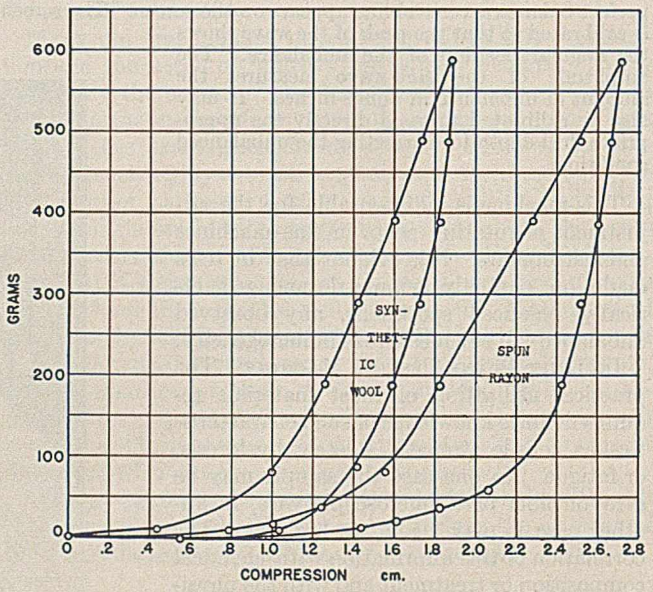
In the cases shown, the hysteresis or lack of resiliency is given quantitatively by the area enclosed by the loading-deloading lines.

Numerous applications of this instrument have been described by its inventor (*36, 37, 41*).

EVENNESS TESTER. An instrument for detecting variations in thickness of yarns, lampwire, paper, tapes, and other materials is shown in Figure 108.

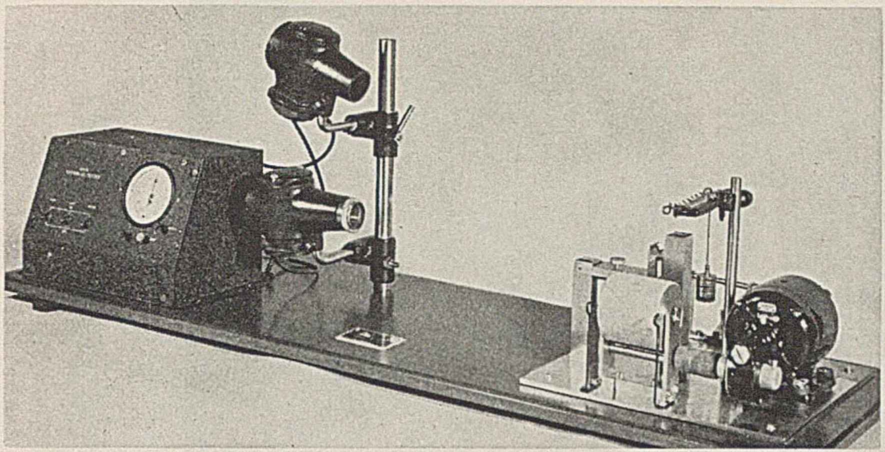
The material is drawn at constant speed and tension through a feeler device which rises if a thick section arrives and falls if the material is too thin. The feeler carries a small mirror which reflects a beam of light to a photocell. Let us assume that the height of the photocell is so adjusted that the light beam is just admitted when the section of material in the feeler is at its nominal value. Any increase or decrease in thickness will move the beam off the photocell. The amplified photocurrent starts an electric clock. For a run of definite time, the reading of this clock will record the fraction of that interval during which the material exhibited the given thickness. By moving the photocell up or down, the frequency of distribution of thick and thin places can be determined.

This instrument and its applications to the general problem of determining frequency distribution have been described in several articles (*38–40*).



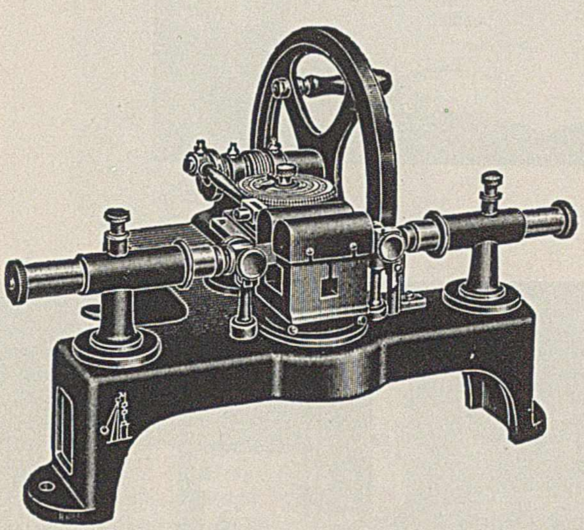
Courtesy, Saxl Instrument Co.

FIGURE 107. LOAD-COMPRESSION CHARACTERISTICS OF SPUN RAYON AND SYNTHETIC WOOL



Courtesy, Saxl Instrument Co.

FIGURE 108. EVENNESS TESTER WITH PHOTOELECTRIC RECORDER



Courtesy, Testing Machines, Inc.

FIGURE 109. FOLDING ENDURANCE TESTER
(Foreign manufacture)

FOLDING ENDURANCE TESTER[1]. A means for determining the folding endurance of paper of all kinds from tissue paper to light board is shown in Figure 109 and is the standard of the Technical Association of the Pulp and Paper Industry.

In this machine, which may be hand or preferably motor-driven, a strip of paper 100 × 15 mm. wide is held at either end by grips under 1000-gram tension. A slotted blade catches the paper in the middle, folding it back and forth until it breaks. The number of double folds sustained by the paper is recorded on the dial. In 1915 the United States Government, Bureau of Standards, adopted this test for the evaluation of currency paper, which under the present requirements must sustain no less than 2000 double folds in either direction to be acceptable. Values obtained by this instrument have been fixed by the Government Printing Office for evaluating the quality of standard papers.

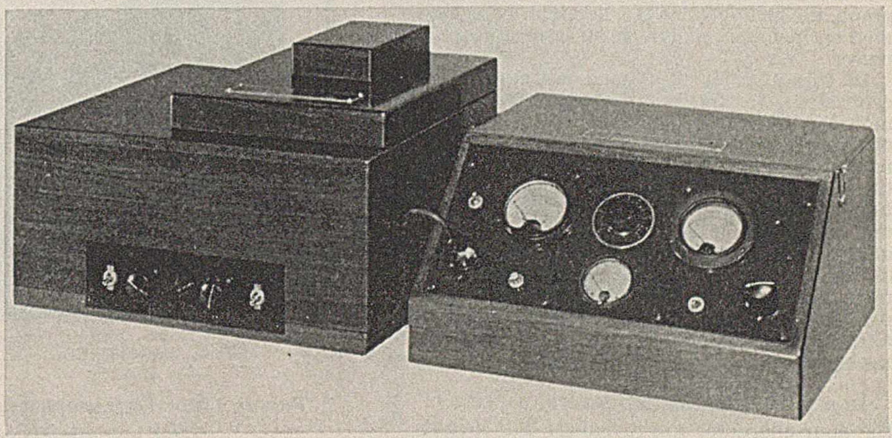
Other instruments have been developed for obtaining related information on materials of this sort, and methods have been devised to interpret and reduce such information to unequivocal terms. Thus in bending fatigue testers it is possible to subject paper and like materials to repeated 90° bends under various loads. The loads are usually chosen in definite fractions of the tensile strength. A linear relation exists between the logarithm of the bending fatigue number and the corresponding permanent load in per cent of the tensile strength. If this line is extrapolated to zero load, the so-called "ideal bending fatigue number" can be determined. This really denotes the number of times a material can be bent to and fro at an angle of 2 × 90° when it is not under tension. This number depends upon chemical treatment, the influence of sizing, etc., but is independent of the formation of a sheet-machine or cross directions, thickness, fiber size, or degree of beating.

The actual individuality of a given sheet of paper may be ascertained in terms of what is called the "bending breaking length". It is that fraction of the breaking length which, when applied as a load, will yield a bending number of 10 (log = 1.0).

THWING FORMATION TESTER. This instrument, shown in Figure 110, measures objectively the quality of paper known to the trade as "formation". The sample is moved at high velocity between a steady light source and a photoelectric cell. The variations in opacity of the paper, which may be due to variations in either thickness or structure, cause a fluctuation in the photoelectric current. The varying current, but not the steady component, is passed on to an alternating current amplifier of suitable frequency characteristics and is read on an output meter. The steady photocell current is indicated on a separate meter. To simplify the procedure, the steady component may be set at a standard value, whereupon the output meter will indicate the formation number of the sample directly. In the illustration, the unit on the left contains the scanning mechanism, and the one on the right, the amplifier and indicating meters.

This instrument illustrates the ease with which a definite criterion can be reduced to measurable and reproducible terms, even though the definition of the quantity in fundamental terms is difficult.

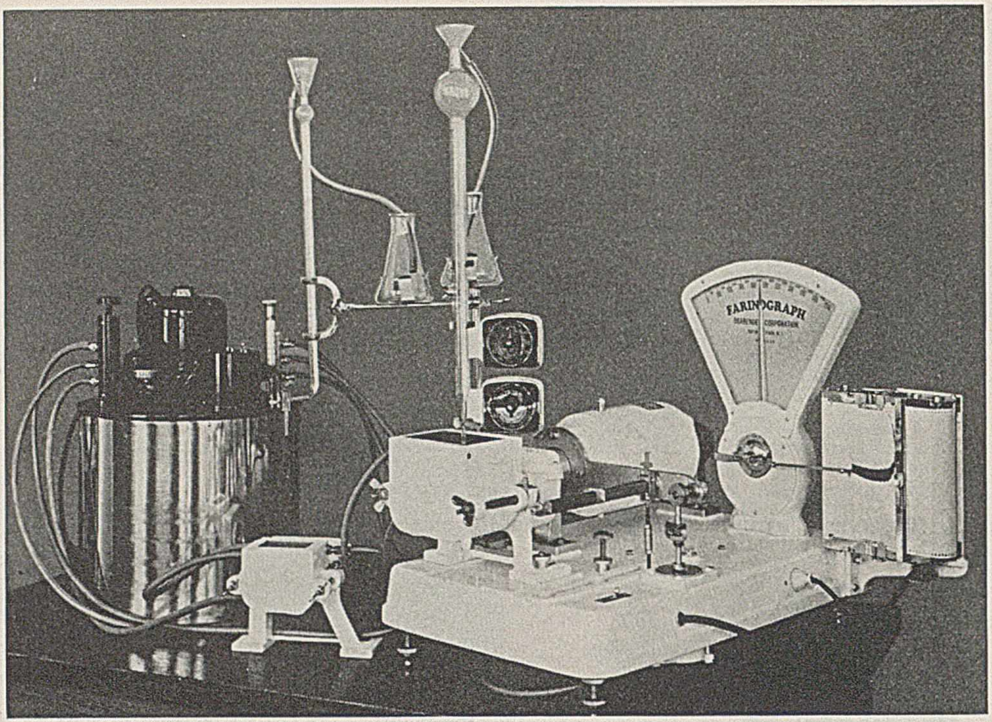
PLASTOGRAPH (FARINOGRAPH). The consistency history of complex mixtures often affords useful information for the



Courtesy, Thwing-Albert Instrument Co.

FIGURE 110. FORMATION TESTER

[1] Foreign manufacture.



Courtesy, Brabender Corp.

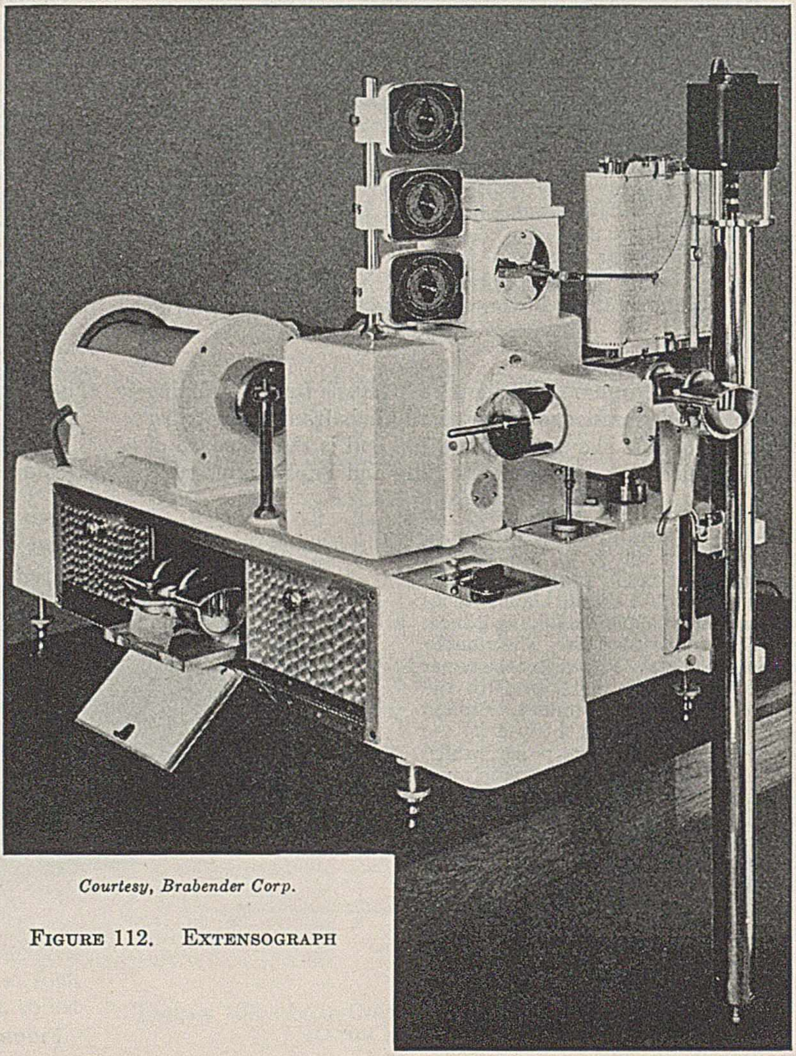
FIGURE 111. FARINOGRAPH

proper utilization of the material. Plastic materials like artificial resins, dyestuffs, greases, clays, starches, and cereals can be studied with profit. While a consistency record involves time as a variable, the effect of temperature, water absorption, or the addition of other ingredients may well be the independent variable.

The farinograph shown in Figure 111 is a form of plastograph for obtaining information of use in the baking industry. Dough structure is characterized by its ability to absorb more or less water (absorption consistency), to resist mechanical abuses for a shorter or longer time (development, stability, weakening), and to give a larger or smaller volume (elasticity, distensibility). The farinograph measures and records these factors over a certain range of time. If the gassing power of the dough is measured under comparable conditions, which can also be done automatically in the fermentograph, the baking value of a flour can be evaluated on the basis of dough structure: gassing power.

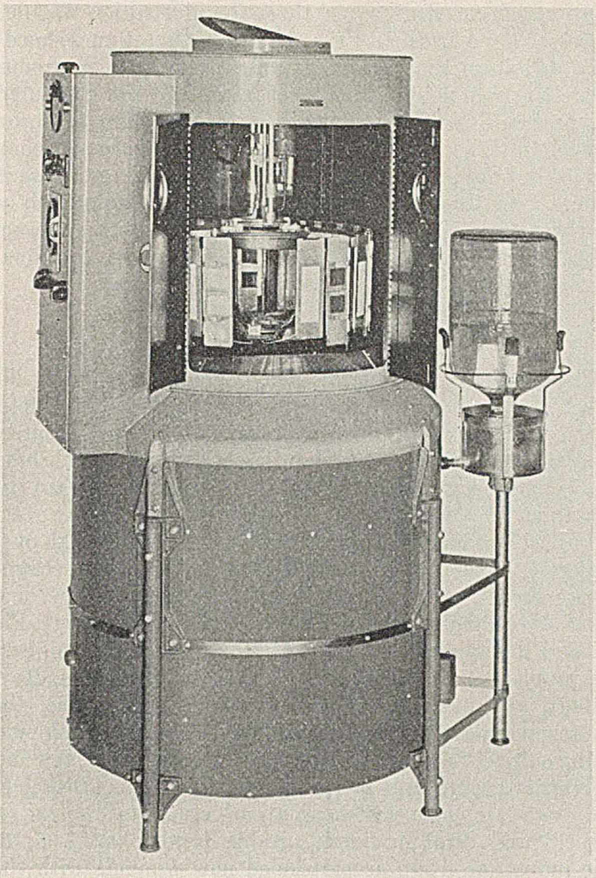
In this instrument a small mixing bowl is connected to a freely swinging dynamometer mounted in ball bearings. The resistance which the dough exerts toward mixing is transferred to the dynamometer, which tends to equalize this resistance by turning in the opposite direction. The resultant thrust is transmitted to the scale system through levers. The end of the primary lever is coupled to an oil-damping dash pot to iron out abrupt oscillations. The scale system is fitted with recording pen and chart. Constant temperature is maintained in the mixing bowl and oil damper by the thermostat shown on the left.

In a typical farinogram several aspects of the flour character are revealed: The height of the curve measures dough consistency, the time required to reach this height reveals dough development, the interval through



Courtesy, Brabender Corp.

FIGURE 112. EXTENSOGRAPH



Courtesy, Atlas Electric Devices Co.

FIGURE 113. FADE-OMETER

which this maximum reading persists measures dough stability, the width of the recorded envelope measures elasticity and distensibility, and the extent to which the reading eventually recedes from the maximum indicates weakening of the dough.

When properly correlated with fermentation-rate data, this information predicts baking qualities of a flour and indicates to the expert the appropriate fermentation, kneading, and baking time to secure the best results. It is said to eliminate the need for the sole reliance previously based on baking tests. Another advantage lies in the ability to blend strong and weak flours to yield doughs of acceptable characteristics.

EXTENSOGRAPH. As one might expect, a single physical characteristic of material as complex as dough is of limited value. The values furnished by the farinograph are characteristic of the dough in a dynamic or "excited" state. After resting it may show markedly different properties; something akin to "work hardening" has occurred.

The extensograph shown in Figure 112 supplements the findings of the farinograph in this respect. After a specimen of dough has been mixed in the farinograph under controlled conditions it may be formed into an appropriately shaped "billet", firmly clamped in the dough holder, and placed in the thermostat or fermentation cabinet for a definite time. After the selected resting time, the holder with its sample is placed in the rack (upper right) where a hook engages the mid-section of the dough and proceeds to stretch it at a uniform rate. The recording pen and chart draw the resulting force-extension curve. Evaluation of the dough is based on the area under this curve.

Measurements of this kind have been reported for typical American wheats in a recent paper (*31*). The general technique of the plastograph is capable of wide application; a recent publication deals with its use in a study of highway subgrade soils (*35*).

FADE-OMETER. With the device shown in Figure 113 the resistance to fading of colored materials can be determined.

A rotating drum carrying the samples assures uniform illumination at a constant distance from the glass-enclosed carbon arc. The radiation is comparable to that from the sun and permits an accelerated test of light sensitivity of the material. During exposure, the samples are maintained at constant temperature and humidity. The device is widely used in accelerated tests on textiles, dyestuffs, wallpaper, printing ink, and rubber products.

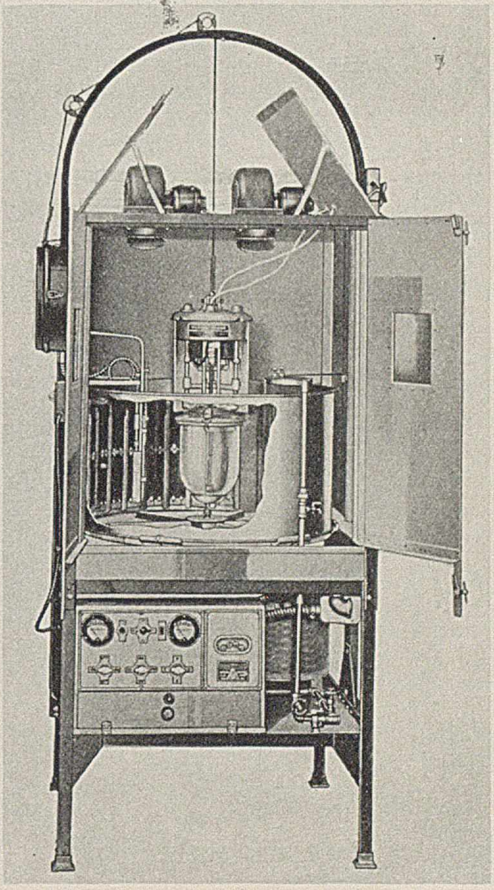
The testing methods and procedures of several groups such as the American Association of Textile Chemists and Colorists, American Society for Testing Materials, National Bureau of Standards, and Federal Specifications Board include tests based on this machine.

WEATHER-OMETER. More extensive tests, suitable for evaluating the effect of several factors on the reliability of materials, can be made with the Weather-Ometer shown in Figure 114.

This self-contained unit consists of a carbon arc light source, a heavy spray of water to simulate the mechanical action of rain, and a mild spray to produce humidity. The samples can be subjected to alternate dryness and high humidity, enhancing the thermal shock and expansion and contraction. Oxidation can be accelerated by the use of ozone. The samples are mounted vertically on a rotating drum and full control over the chosen conditions can be maintained by means of the instruments on the control panel.

Service failure of all materials intended for outdoor use may be duplicated rapidly in this machine, which is particularly convenient for studying paint, varnishes and lacquers, enamels, asphalts, roofings, plastics, rubber, etc.

Another useful machine in the same category is the Launder-Ometer, a standard laboratory washing machine which operates

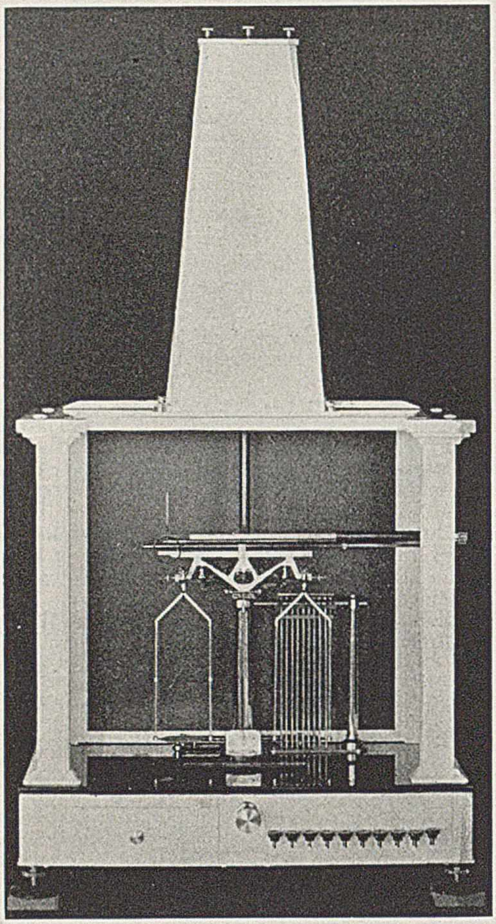


Courtesy, Atlas Electric Devices Co.

FIGURE 114. WEATHER-OMETER

under constant temperature, speed, and character of agitation. Under carefully specified conditions as established by the A. A. T. C. C. it makes possible a reproducible evaluation of color fastness, staining, detergency, shrinkage, and related qualities.

We have considered relatively few instruments and machines devoted to the general problem of interrelating two or more variables. In some of these the illustration was deliberately chosen because the property in question seemed to defy definition, much less promise accurate measurement. There has been no dearth of mechanical skill and ingenuity in the past in designing instruments and machines to perform difficult tasks. The resources of the present are so rich and full of subtle promise that one may expect startling advances. In this respect the cathode ray oscillograph will bear watching. Without moving parts, and with almost unlimited versatility, it will be the basis of many coordinatographs of the future.



Courtesy, Wm. Ainsworth & Sons, Inc.

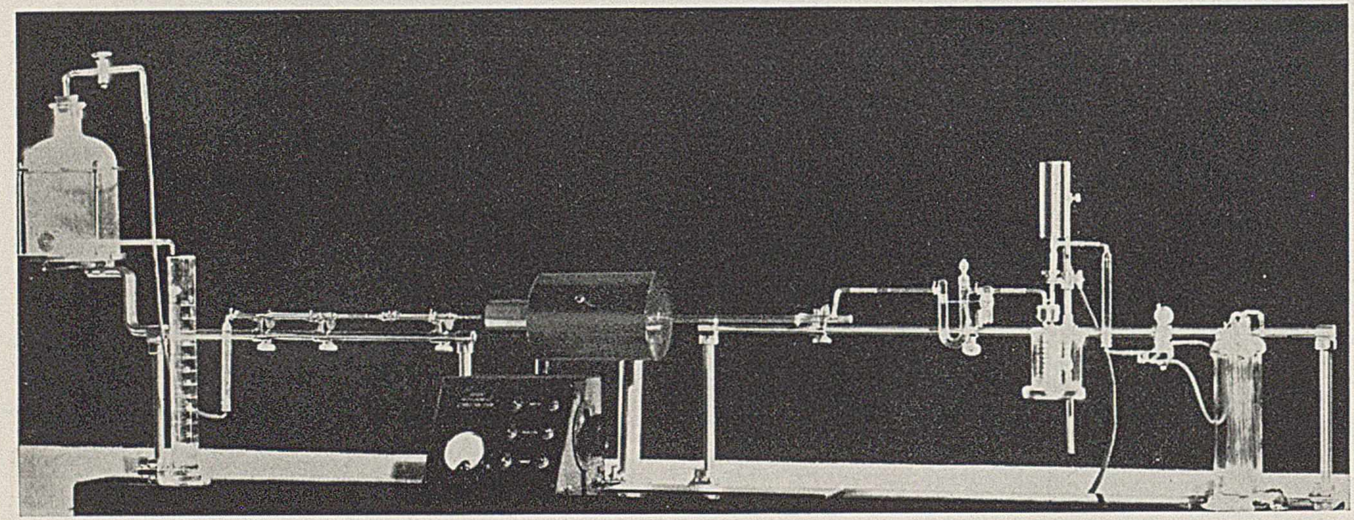
FIGURE 115. MICROBALANCE WITH AUTOMATIC WEIGHT CARRIER

Microchemistry

The excellence of American microchemistry is amply illustrated by the number of articles published on this subject, the many laboratories devoted to this work, and a degree of general interest in the field which justified the establishment of a separate section under that heading in the ANALYTICAL EDITION.

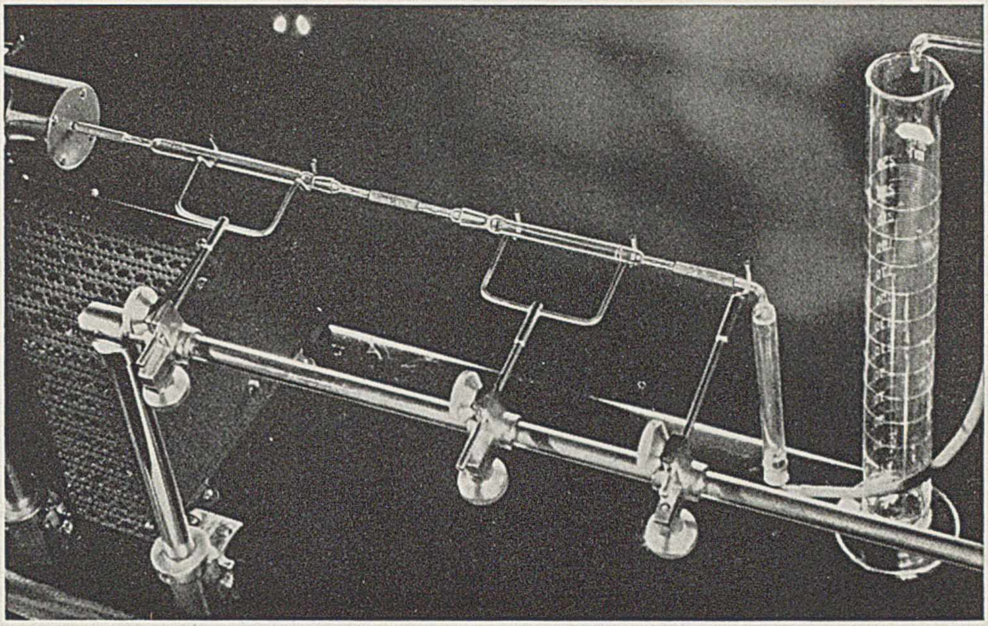
Several factors have contributed to the rapid growth of this subject—the pioneer work of Chamot and Mason in chemical microscopy, the early introduction into this country of the methods of Pregl and Emich by Niederl and Benedetti-Pichler, and the application and extension of these techniques to the problems of industry by Clarke and Hermance, Royer, Hallett, and others. Aside from their publications, these investigators laid the foundations for the sound development of the subject in several ways. The Cornell and New York University groups established thorough courses of instruction and with an enthusiastic group of students "spread the gospel" and also provided suitable textbooks (*4*, *5*, *34*). The industrial group accomplished new wonders with these techniques and effectively sold them to responsible management.

The apparatus and instrument makers of the country have not been slow to respond to the interest in microchemical methods. Microscopes in great variety and with appropriate accessories are available, reliable microbalances have been designed and manufactured, and most dealers and supply houses list all the glassware, tools, and minutiae essential for this work. In characteristic American fashion, the initial policy of duplicating and copying the standard apparatus was soon discarded and the newer offerings are modernized, more desirable and efficient, standardized, and in general tending toward our usual goal—better and yet cheaper.



Courtesy, E. H. Sargent & Co.

FIGURE 116. CARBON-HYDROGEN MICROAPPARATUS



Courtesy, E. H. Sargent & Co.

FIGURE 117. DETAIL OF CARBON-HYDROGEN MICROAPPARATUS

The Ainsworth microbalance (Figure 115) illustrates some of the advances which have been made. It has a capacity of 20 grams on each pan with a sensitivity of 10 divisions for 0.01 mg., permitting estimation in fractions of a microgram. An optical lever is used instead of a reading lens, eliminating errors due to parallax. A narrow, intense beam of light moves across a zero center scale having 100 divisions on each side. Each division is 0.5 mm. wide and corresponds to 1 microgram. A keyboard-operated weight carrier avoids handling all fractional weights up to and including 100 mg., making available a total of 221 mg. This arrangement assures remarkable constancy of these weights over long periods of time. A special model of this balance for work of the highest precision is provided with a weight carrier on both sides, which permits rapid intercalibration of the fractional weights under ideal conditions.

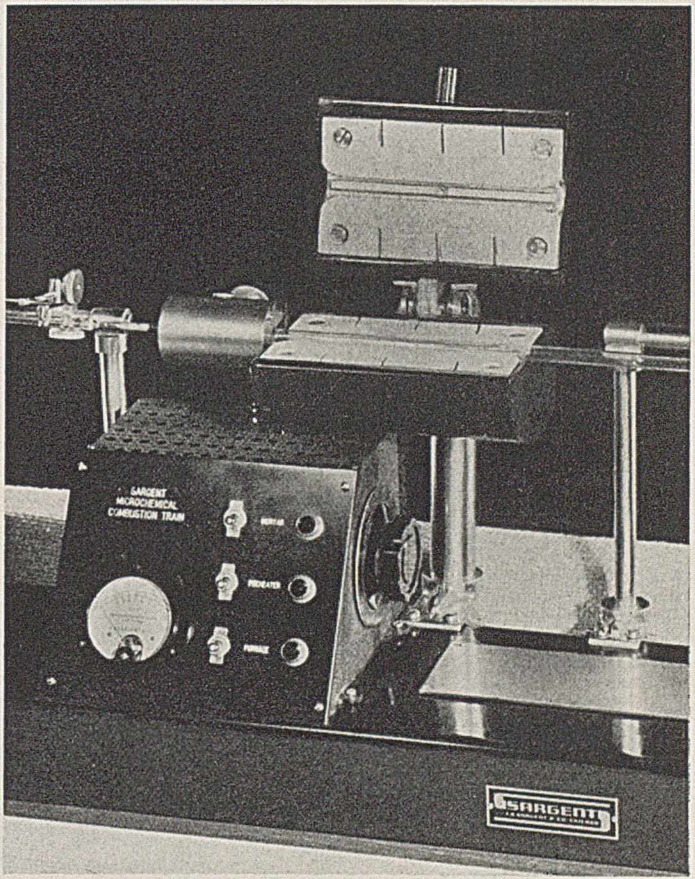
UNIVERSAL CARBON-HYDROGEN MICROAPPARATUS. The modern and efficient unit shown in Figures 116 and 117 was designed by E. H. Sargent & Co. to accommodate the glass parts of all the commonly employed combustion trains, and to eliminate the unstable and inconvenient support arrangements heretofore used.

In addition to the heavily plated posts, rails, and supporting clamps, the apparatus contains a specially designed furnace, with the winding tapered for most efficient heat distribution, and with a permanently installed thermocouple in the lower section. The solid brass, chromium-plated mortar contains its own electrical heating element which is controlled by a self-contained thermostat preset at 177° C. The preheater furnace is a tubular unit enclosed by a chromium-plated cylindrical case. It is connected to the switchboard circuit by an individual cord and receptacle in the rear of the base.

The control unit (Figure 118) is provided with individual switches and pilot lamps for furnace, mortar, and preheater. The furnace temperature is controlled by a variable transformer with adjusting knob and index dial. An indicating pyrometer is specially calibrated to read directly the temperature inside the glass or quartz combustion tube.

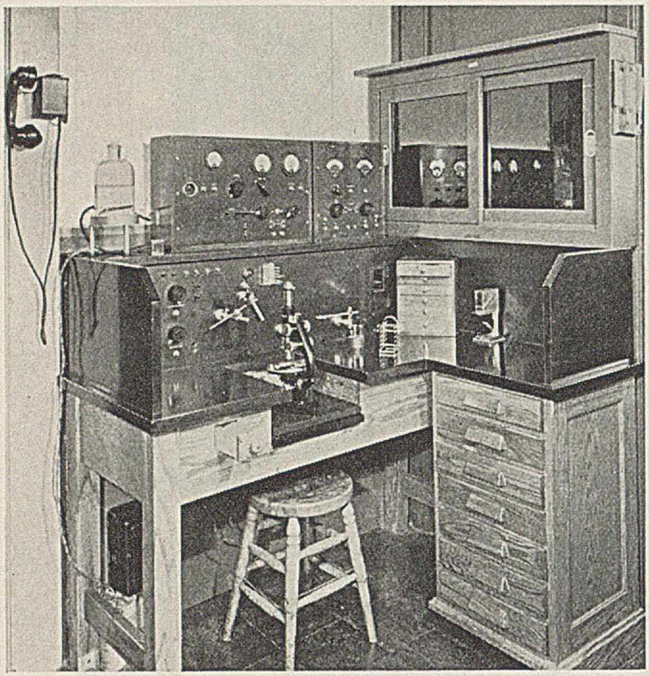
This unit is an excellent example of a current trend in the apparatus industry—to reduce a complex array of individual pieces of apparatus to a compact well-integrated unit, and to apply the full resources of modern materials of construction and up-to-date instrumentation.

A TYPICAL INDUSTRIAL INSTALLATION. There are few places, academic or industrial, where microchemistry is



Courtesy, E. H. Sargent & Co.

FIGURE 118. CONTROL UNIT OF CARBON-HYDROGEN MICROAPPARATUS



Courtesy, Bell Telephone Laboratories, Inc.

FIGURE 119. MICROSCOPE BENCH UNIT

studied and applied with greater success than in the Bell Telephone Laboratories. The approach to the subject in the hands of this group is usually unconventional and, as might be expected, highly productive of new techniques and instruments.

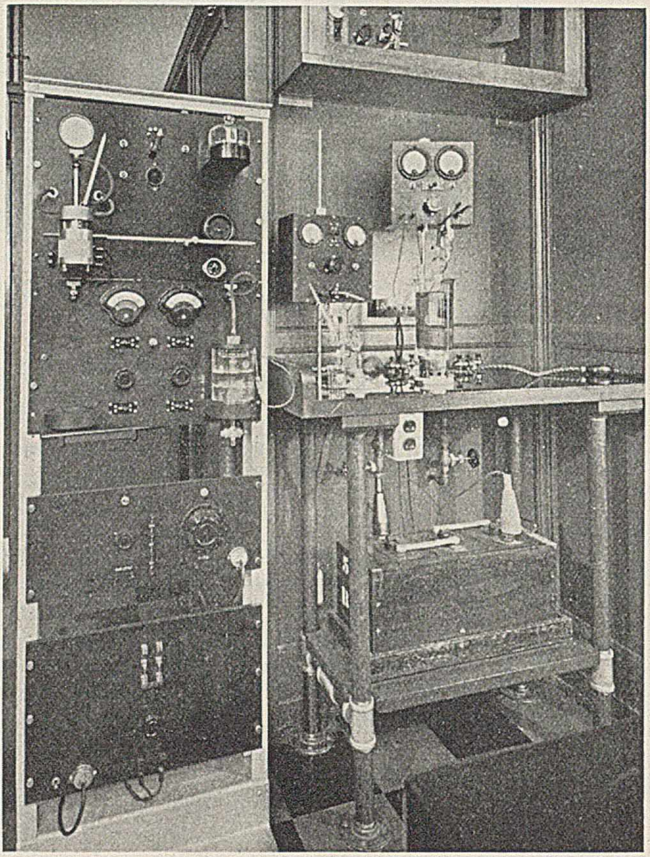
The microscope bench unit shown in Figure 119 was specially designed for the efficient and convenient execution of all operations required in microscopic examinations. The microscope is mounted in an adjustable well, with the stage at arm level. Individual plug outlets at the sides of the well correspond with their color-coded equivalents on the control panel and avoid interfering wires or cables to supply current for stage heating, electrolysis, micro borax bead equipment, and other operations. The choice of illuminants is very flexible with intensity control on the panel. Either direct or substage illumination is available.

Other details and conveniences are apparent in the photograph, such as the built-in drying oven, slide holder and dispenser, rack for capillary tubes, etc. Drawers in the cabinet are specially fitted for all microscope parts and accessories and for reagent vials. Every detail of design is in the interest of neatness, efficiency, and convenience, in the presence of which chemical microscopy is so valuable, and without which it is a waste of time.

Figure 120 illustrates another section of the microchemical laboratory. The two electrolytic units on the table at the right are control units for the well-known Clarke and Hermance microelectrolytic cells for both small and large volumes of electrolyte. The complete self-contained control units may be raised from the permanently mounted support rods and stored away from deleterious fumes.

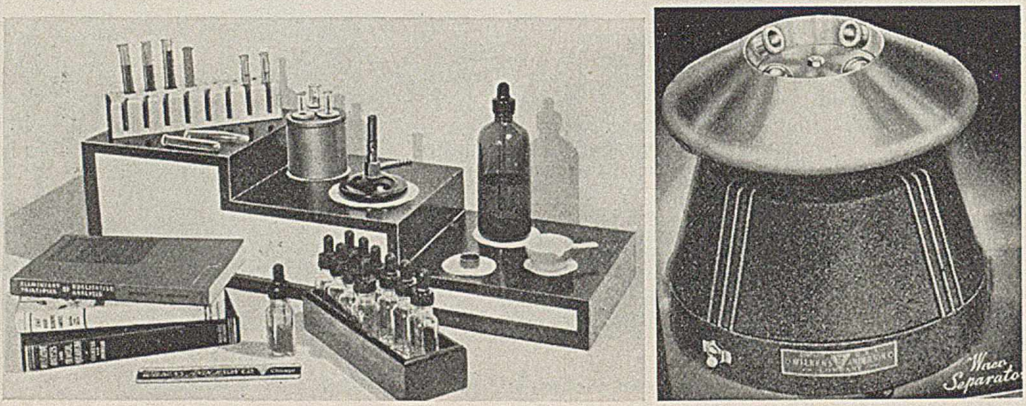
At the top of the panel unit on the left is the sublimation microapparatus with accompanying switches, pilot lamp, thermometer, control rheostat, vacuum cock, and vacuum gage. On the panel below is another electrolytic cell, using a mercury cathode. Multirange volt and ammeters and the necessary switches and controls are integral components. The radio relay-rack on which this apparatus is mounted marks the happy marriage of radio engineering and chemistry—not strange in an organization devoted to communications research, but indicative of the profit one may derive from the resources of another field. To chemists who are acquainted with the tenpin propensities of glassware, this type of installation promises happier times.

Space limitations prohibit the discussion of many other developments from this laboratory. Fortunately, Clarke,



Courtesy, Bell Telephone Laboratories, Inc.

FIGURE 120. MODERN INDUSTRIAL MICROCHEMICAL APPARATUS



Courtesy, Wilkens-Anderson Co.

FIGURE 121. SEMIMICROAPPARATUS AND SEPARATOR USED FOR INSTRUCTION

Hermance, and their co-workers have discussed some of them in recent papers (*7*, *8*).

SEMIMICROAPPARATUS. Despite the fact that "semimicro" is anathema to some professional microanalysts, its advantages seem to be increasingly appreciated by educational institutions. Many of them have abandoned macromethods for teaching qualitative analysis, in the interest of economy of time and material and in improved performance on the part of the students. Textbooks on semimicromethods have been published from Chicago, Duke, Oklahoma, Purdue, and New Hampshire.

Apparatus manufacturers and dealers have assisted greatly in offering convenient student kits and accessories, a typical example of which is shown in Figure 121. With the aid of the separator or medium-speed centrifuge many filtering operations can be eliminated. The compact, self-contained water bath, semimicroburner, and convenient test-tube and reagent block emphasize the adaptation of equipment to the problem in hand.

It is undoubtedly true that this technique promotes more careful work on the part of the student and introduces him to some of the subtleties and niceties requisite for true microanalysis.

General Laboratory Appliances

Practically every appliance in the laboratory is subject to constant study for improvement. Apparatus and equipment manufacturers have expended considerable time and effort in making the environment and working facilities of the chemist more efficient and reliable. We may mention a few of the aids which have been offered recently.

BARNSTEAD FULL-AUTOMATIC WATER STILL. The distilled water unit shown in Figure 122 represents a number of improvements for producing distilled water of high purity.

The evaporators in Barnstead stills have been redesigned and reproportioned to permit distillation at lower vapor velocity and to provide increased steam disengaging space. Extremely low vapor velocity prevents entrainment of impurities in the vapors. The evaporators have also been made more accessible for cleaning purposes, and heating elements have been developed which are removable from the sides of the evaporator without dismantling the equipment.

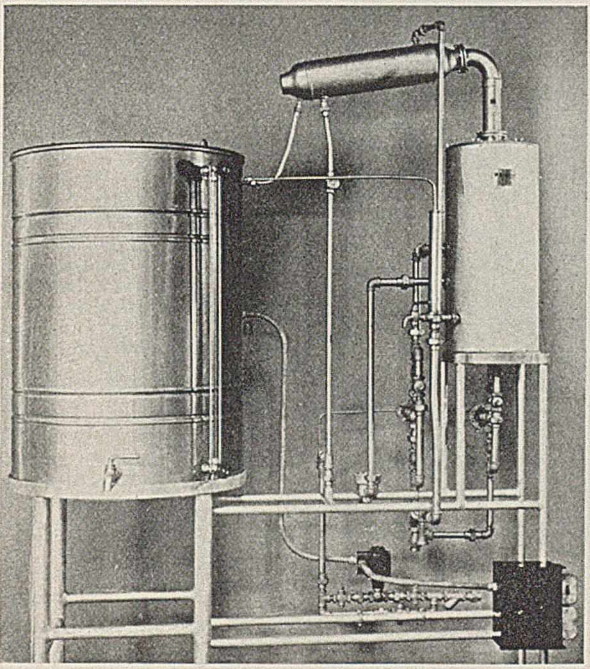
The system illustrated here is fully automatic, self-starting, self-stopping, and flushing, with appropriate controls such that the Barnstead water still and storage tank can be mounted in combination and will operate entirely without attendants. The still is started and stopped automatically, controlled by the distilled water level in the storage tank, and the evaporator is automatically drained and flushed of sediment at regular intervals. This system is particularly useful when designed to provide a central source of distilled water for a distribution system.

Courtesy, Industrial Instruments, Inc.

FIGURE 123. AUTOMATIC DISTILLED WATER CHECKER

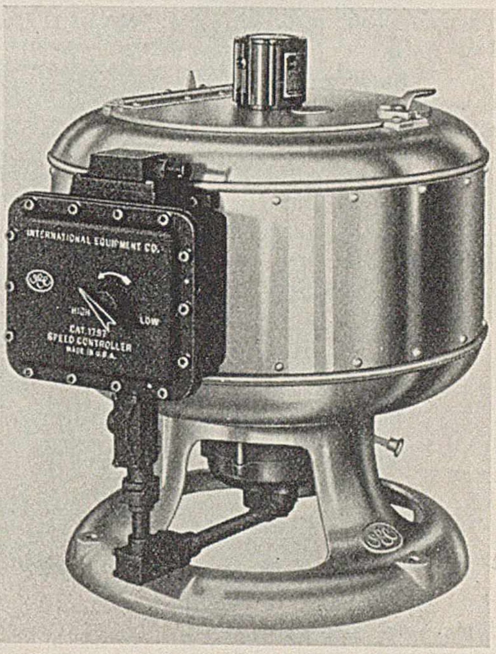
This is one of a complete line of still equipment which includes triple stills, special stills for conductivity water, etc., for either manual or automatic operation and fitted for gas, steam, or electrical heating.

AUTOMATIC DISTILLED WATER CHECKER. Distilled water may be appraised by various criteria, depending on the use to which it is to be put—i. e., electrolytic, gaseous, and pyro-



Courtesy, Barnstead Still & Sterilizer Co., Inc.

FIGURE 122. FULL-AUTOMATIC WATER STILL



Courtesy, International Equipment Co.

FIGURE 124. CENTRIFUGE

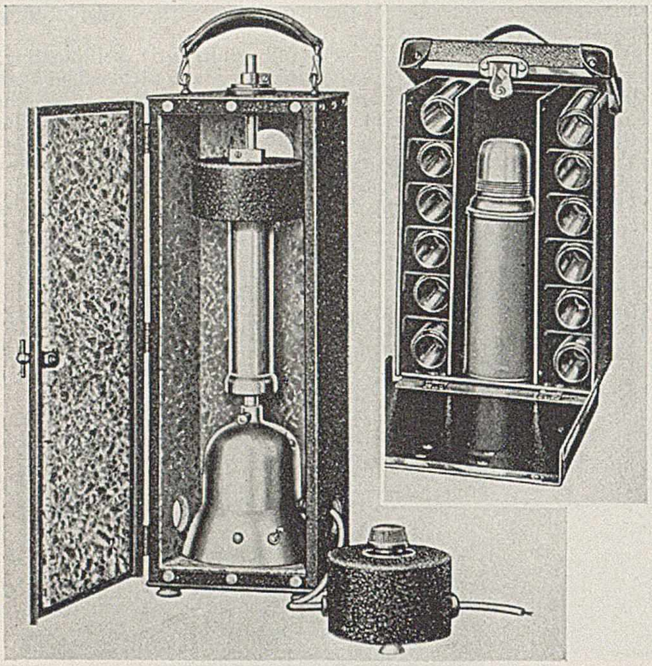


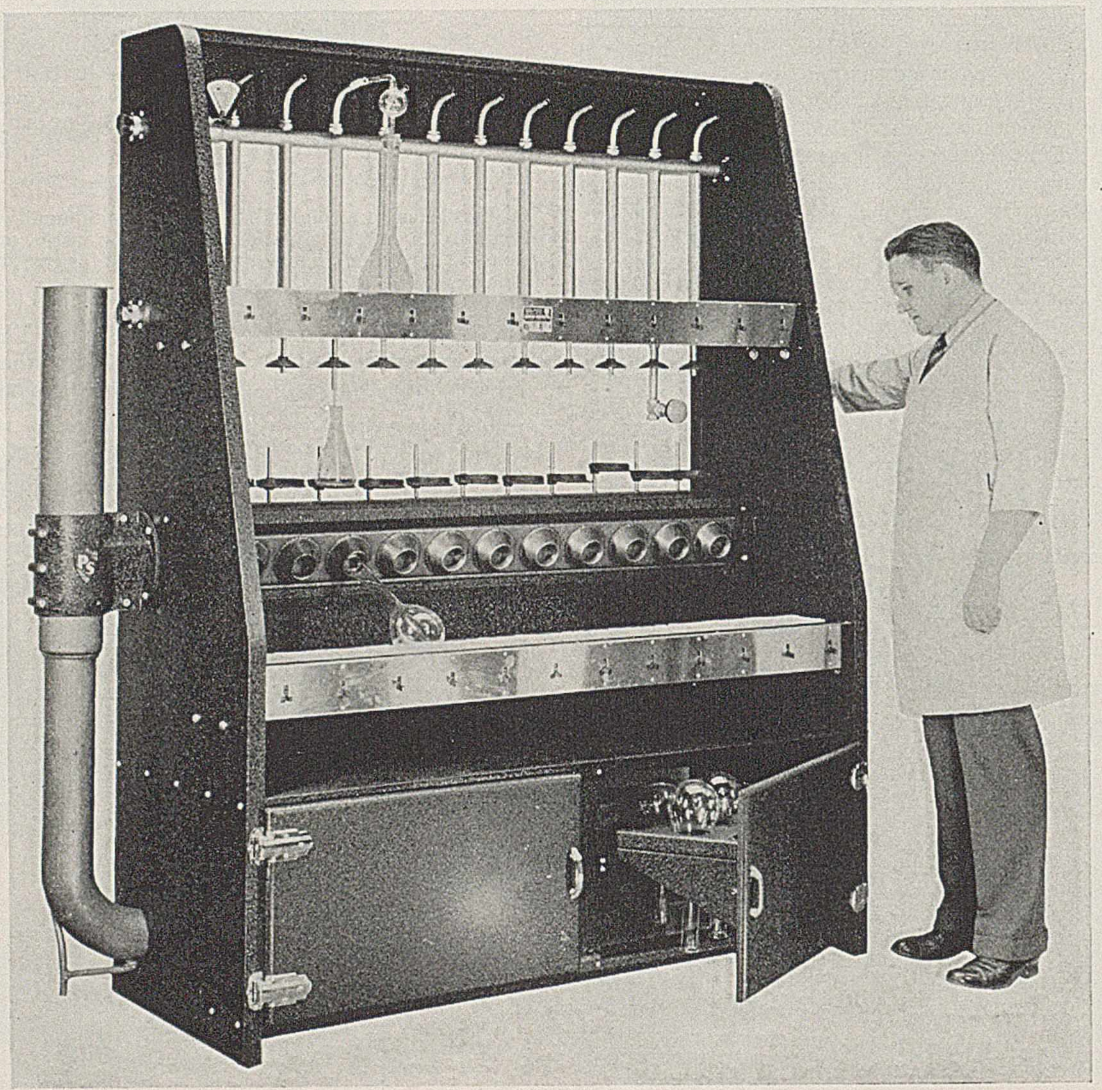
Figure 125. Wells Air Centrifuge
(*Upper right*) Carrier for Hot Nutrient Medium and Sterilized Tubes

Courtesy, International Equipment Co.

genic impurities. In general the electrolytic conductance is a fairly reliable measure of the quality of distilled water.

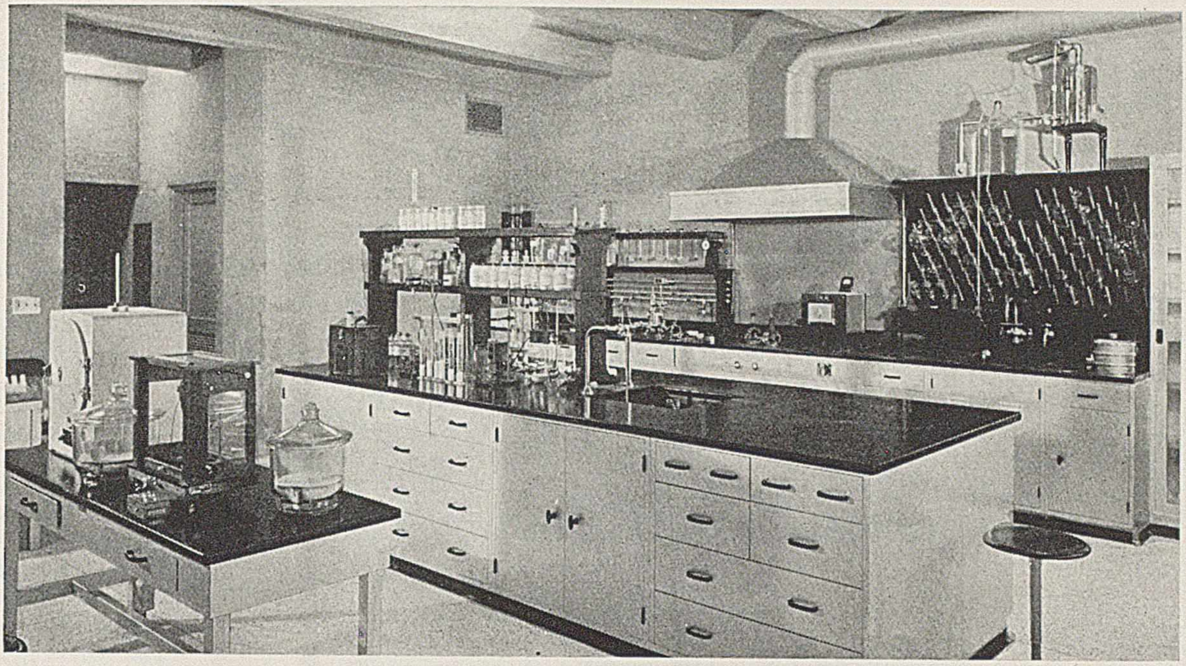
The instrument shown in Figure 123 is designed for the continuous measurement of the conductivity of water and in addition to the continuous indication may be used to sound an alarm or divert the water to waste if it exceeds the arbitrarily set requirements. The instrument is an electronic conductivity bridge fully alternating current–operated with a built-in voltage regulator to assure accurate calibration. The meter is calibrated in parts per million of chloride ion. The conductivity cell screws into a standard connection in the pipe line or tank containing the distilled water. A 1-inch magnetic valve is available as an accessory and if desired may be installed in the pipe line to drain the water whenever the output is unsatisfactory. The instrument is housed in a steel cabinet for wall mounting in any desired location.

International Centrifuge. The centrifuge shown in Figure 124 is one of many versatile units made by the International Equipment Company, which can be fitted with a variety of heads or with centrifuge baskets.



Courtesy, Precision Scientific Co.

Figure 126. Combination Kjeldahl Equipment for Digestions and Distillations



Courtesy, Kewaunee Mfg. Co.

FIGURE 127. MODERN LABORATORY FURNITURE

It is furnished with an explosion-proof 3450 r. p. m. motor, a completely enclosed speed regulator, and an indicating tachometer which is mounted on the lid. The dial of the tachometer is graduated from 0 to 6000 in steps of 100 r. p. m. Contact is established between the tachometer shaft and the tube carrying head by means of a rubber tip.

WELLS AIR CENTRIFUGE. This instrument, shown in Figure 125, is made by the same company and is introduced to meet the need for a convenient, portable, electrically driven tester to facilitate the collection of bacteria from samples of air in the field by centrifugal precipitation upon a nutrient medium. This centrifuge has been included in a standard procedure for air investigation and is described by Wells *et al.* (*49*).

The device consists of a motor-drive unit upon which rests an aluminum cylinder with a fan above it. Sterilized glass tubes are placed inside the cylinder and, in operation, air drawn in by the fan is swirled around, bacteria being driven centrifugally to the walls of the glass tube. Just before use 20 to 25 ml. of melted agar-base nutrient medium are added from a vacuum bottle to the glass tube. In operation this medium flows smoothly over the inner surface of the tube and hardens thereon. The bacteria are collected directly by centrifugal force on the hardened medium while the air is being drawn through the tube. At the end of the run the glass tube is removed, sealed, and placed in the carrying base, which with the thermos bottle for the hot nutrient is shown at the right. A manometer is provided for measuring the rate of air flow and its readings can be interpreted from a chart mounted on the door of the centrifuge.

The instrument is designed primarily for field use and can be used wherever electric current is available, as in school rooms, theaters, hospitals, public buildings, and subways. If work is to be done in the laboratory with pathogenic organisms, a large gas-burner attachment may be mounted on the outlet to the fan housing, thus ensuring the destruction of the pathogens.

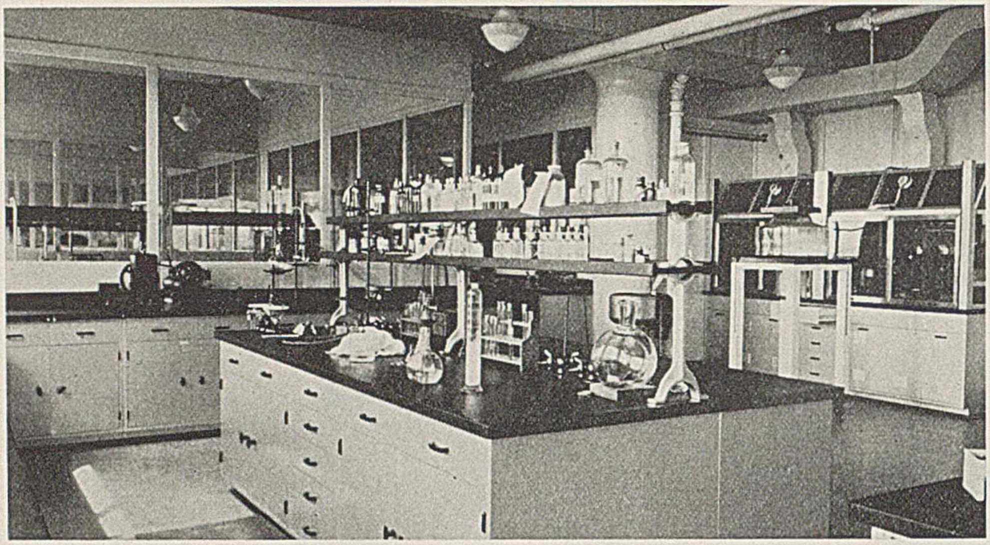
KJELDAHL EQUIPMENT. The Precision advance model combination Kjeldahl equipment for digestions and distillations shown in Figure 126 has twelve units each, with multitube distillation bank and multihood digestion bank heated by individual electric heaters, with separate 30-ampere double-pole switch for each heater. The multihood fume-exhaust manifold and vertical stack are built of tellurium lead. Equipment of this type is also built in smaller or larger assemblies in multiples of six units.

LABORATORY FURNITURE. There is no question that the quality and quantity of work emanating from a laboratory depend to a large extent on the convenience and utility of the general equipment. Great strides have been made in laboratory furniture of all kinds in which elegant and pleasing appearance is a welcome by-product. The use of stainless and corrosion-free materials is very extensive and has direct bearing on the quality of the work which can be done. Typical illustrations of modern laboratories are shown in Figures 127 and 128. For some years the ANALYTICAL EDITION has devoted a few pages in each issue to a description of new laboratories and there is hardly one which does not contain some new and useful suggestion.

LABORATORY AIDS. There are numerous pieces of apparatus in every laboratory, some of which have come down to us practically unchanged from the earliest chemists. Some of them are still crude and inefficient and constant sources of annoyance. Practically all apparatus manufacturers are constantly developing new pieces of equipment or improving the old ones. A few examples of parts which are helpful in taking some of the "cussedness" out of the inanimate are shown in Figure 129.

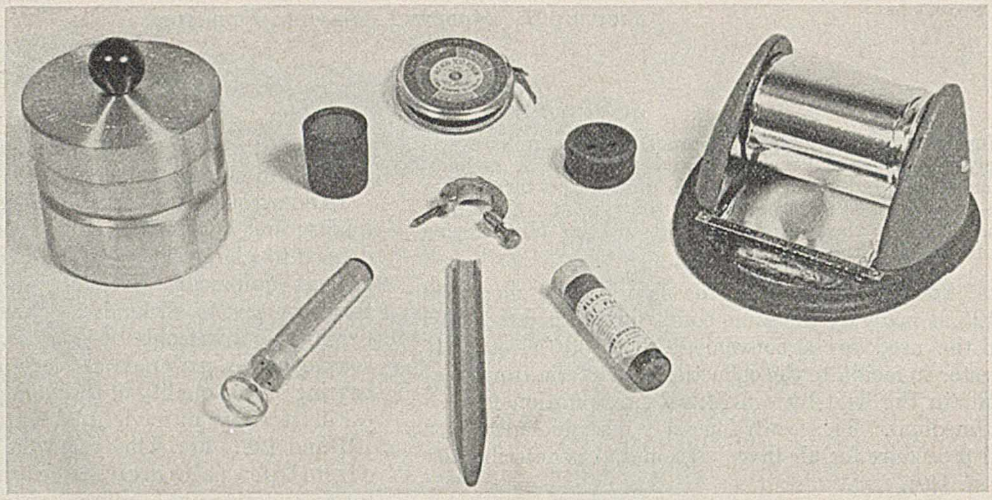
The Desicooler, a spun-aluminum equivalent of the heavy and breakable glass desiccator; Alkacid paper in strips, which is in effect the equivalent of a universal indicator; Alkacid dispenser, which is the same in ribbon form on a reel; the Scoopula, a convenient stainless steel tool combining the properties of a scoop and a spatula; the "no-pop" rubber stopper for wash bottles; the aluminum foil dispenser; the buret regulator, a very ingenious clamp which permits the automatic positioning of the stopcock in two locations, one for fast delivery, the other for dropwise delivery; and a pipet filler, particularly valuable for dangerous or poisonous liquids.

It might be inferred that these advances are small and inconsequential and that almost anyone might think of them. Actually, they represent a great deal of thought and development work before they are suitable for general use. Their



Courtesy, Kewaunee Mfg. Co.

FIGURE 128. MODERN LABORATORY FURNITURE



Courtesy, Fisher Scientific Co.

FIGURE 129. LABORATORY "WIDGETS"

value is best attested by the tremendous demand whenever a real time- or labor-saving item of this kind is introduced.

Industrial Design

Industrial designing is an important profession, the purpose and intent of which are frequently misunderstood. Although engineers were at first reluctant to cooperate with artists, in the sense that they resented attempts to "prettify" their prosaic instruments and machines, these two groups now enjoy the most cordial relations, because the true function of industrial design is to select materials of construction and general lines of the instrument or machine to conform to strictly functional principles.

The modern designer concerns himself first of all with the nature of the machine, its intended purpose, and the exact sequence of operations. His problem is to find a form and a suitable medium in which to express it, so that the final product shall be not only pleasing in appearance but most convenient and efficient in operation. His services to conservative engineers have been successful and he enjoys their full confidence; he has had a hand in the design of stream-lined locomotives, motor cars, machine tools, and other robust structures with which no one would have the temerity to associate long-haired artists.

Recent works have discussed this problem in detail and have indeed developed a whole philosophy of design and extrapolated its effects on the future of our mechanized civilization. Teague (*47*) is particularly concerned with these aspects of the problem. His book is rich in illustrations, presenting a convincing argument that modern design is changing the ugly machine of the 19th and early 20th centuries into a thing of beauty. More directly concerned with the actual details of industrial design and more or less detailed description of the techniques is Van Doren (*48*). Of less direct interest but with the same general theme is Norman Bel Geddes' "Magic Motorways" (*11*), which represents an elaboration of his spectacular panorama at the 1939–40 World's Fair in New York.

Some of the instruments illustrated in this review show the effects of due consideration for these important details.

Practically all modern instruments show a degree of simplicity in line and the absence of ornate embellishment; a plain exterior often hides added complication, but in the interest of ultimate simplicity in operation. This is best illustrated in that most complicated of all modern devices, the broadcast receiver.

Training in Instrumentation

There seems to be complete unanimity of opinion among instrument manufacturers, consumers, and a few of our educators that the graduates of our educational institutions are woefully ignorant of instruments. As a rule they are aware of the purpose for which an instrument is used but they rarely know very much about its construction, the principle on which it is based, or its comparative value among instruments of the same general class. Perhaps one of the difficulties is the emphasis which is placed on laboratory work, where the object is more frequently to confirm some fundamental law or principle. If the student's belief in some of the time-honored laws and general principles were to be based solely on his experimental verification thereof, he could be expected to have very little abiding faith in their essential truth. As a rule when the suggestion is made that more emphasis be placed on the acquisition of skill and a sound technique, the academic retort is, "Oh, you want to breed a race of technicians who have little comprehension of what they are doing." The author submits that there are few cultural or intellectual fields that do not require a definite degree of virtuosity. In music the aspiring genius must subscribe to a form of slavery which extends from the cradle to the grave. If he renounces this discipline and its multitudinous exactions he will never reach the concert stage. He may, of course, derive some diluted satisfaction from becoming a critic.

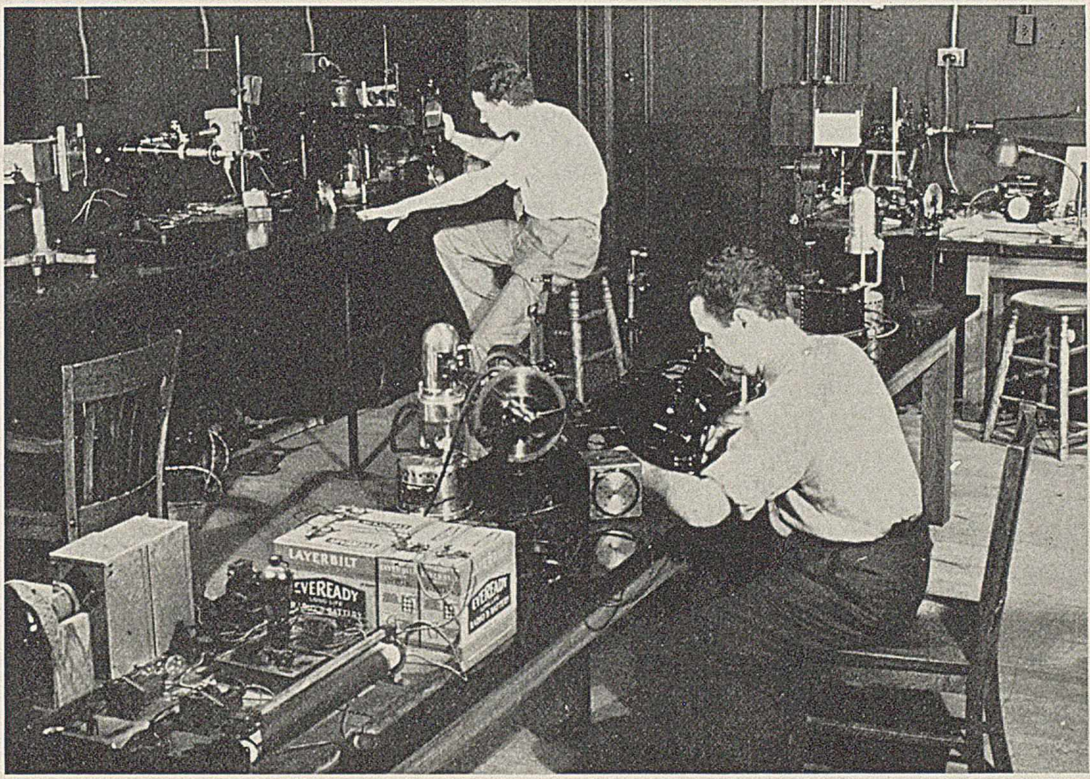
The plea can always be made that given a sound theoretical background the student can readily acquire specialized techniques as he needs them. Fortunately for our personal welfare, this principle has not been adopted by those who are responsible for the curriculum in our medical schools.

Some important work is being done in several institutions where the importance of modern instrumentation is recognized, and for a long time the problem has not been so serious in our engineering schools, where the nature of the subjects perforce requires considerable contact with instruments of all kinds. Figures 130 and 131 are illustrations showing laboratories that are devoted to instruction in instrumental methods.

Instruction in Instrumentation. An excellent example of facilities for teaching instrumental methods is shown in Figure 130, which depicts the optical section of the Laboratory of Physical Chemistry at Columbia University.

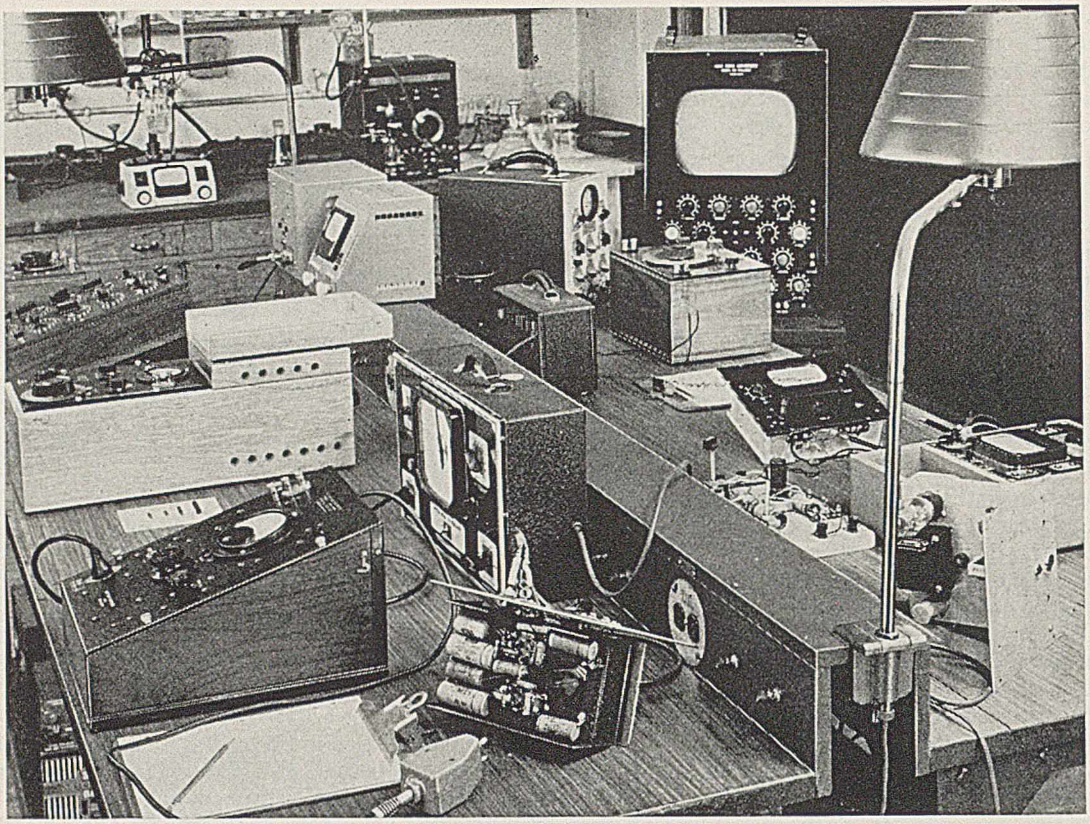
This laboratory has all the usual service facilities—water, gas, compressed air, steam, and 110–220 volts alternating and direct current. This particular section is finished in dead black for convenience in optical work. Proceeding in clockwise fashion from the upper left one may see a Hilger small quartz spectrograph; a Schmidt and Haensch spectrophotometer; a Bausch & Lomb spectrometer with camera attachment; a Hilger medium quartz spectrograph with excitation equipment and rotating sector; a Klett photoelectric colorimeter; a Pulfrich refractometer with sodium arc source; a Bausch & Lomb refractometer, Abbe style; a Schmidt and Haensch polaroscope with sodium arc source; and in the foreground a photoelectric radiation integrator.

The instruction in this course is rigorous and the student is expected to become thoroughly familiar with the principle of operation of each instrument and to be able to evaluate the source and magnitude of all errors. The general assumption is made that with high-class precision equipment, first-class results are to be expected. In general, the successful conclusion of work in a course of this type can be expected to fit the student with the necessary techniques for the competent prosecution of a research problem.



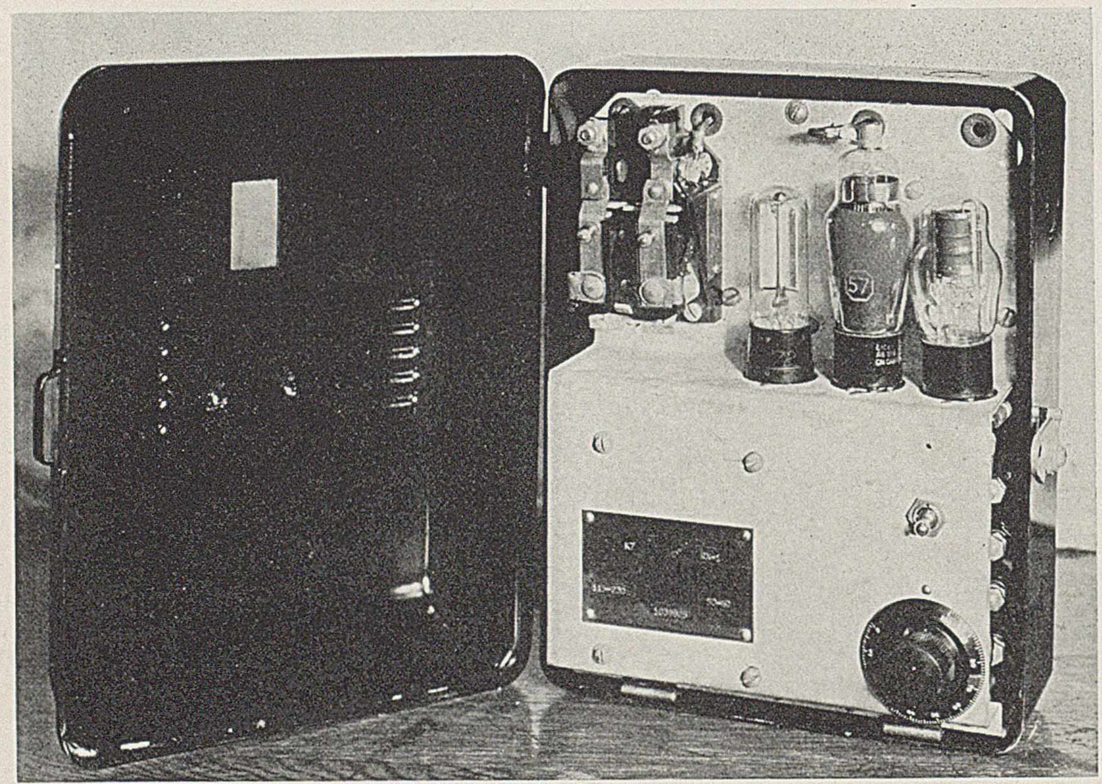
Courtesy, J. J. Beaver, Columbia University

Figure 130. Instruction in Instrumentation



Courtesy, Department of Chemistry, New York University

FIGURE 131. LABORATORY EQUIPPED FOR INSTRUCTION AND RESEARCH IN ELECTRONIC METHODS OF INSTRUMENTATION



Courtesy, Westinghouse Electric & Manufacturing Co.

FIGURE 132. PHOTOELECTRIC CONTROLLER

In Figure 131 is shown a section of the laboratory at New York University devoted to electronic methods and their applications to chemical problems. It illustrates the use of standard commercial instruments in testing and checking experimental units which have been designed and built in the laboratory.

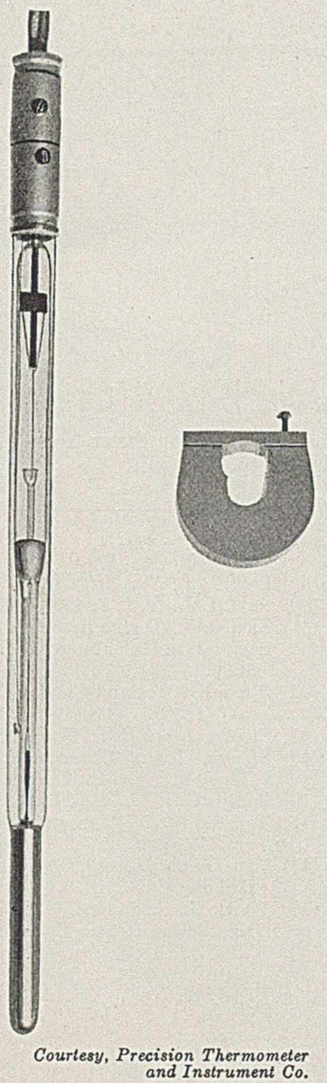
Starting at the left foreground and proceeding clockwise around the center table, we have a Weston signal generator and General Radio vacuum tube voltmeter being used to measure the frequency response of a laboratory amplifier; a General Radio megohm bridge being used to check the value of high resistances; a General Radio bridge with laboratory-built oscillator and bridge balance indicator (these two units are mounted on the ledge); a 3-inch Dumont oscillograph and General Radio audio-frequency bridge used in checking the frequency and wave form of a small R. C. A. beat frequency oscillator; and in the right foreground, two pieces of laboratory-built equipment being checked for circuit continuity and resistance values with a Weston analyzer. In the right background may be seen a large general-purpose oscillograph assembled in the laboratory for some special investigations.

This equipment is used primarily for research, but along with similar equipment, also for instruction in instrumental methods of physical and analytical chemistry.

Addendum

Photoelectric Controllers. For many operations such as counting and sorting, commercially available relay units are offered by several companies. These are to be recommended to the laboratory or industrial worker in preference to homemade assemblies, since they are specifically designed for rugged and dependable performance. The controller shown in Figure 132 is typical of this type of instrument. It is alternating current-operated, requiring a minimum illumination of 1 foot-candle for positive operation. It employs a vacuum phototube, amplifier tube, and thyratron for operating the power contactor.

Precision Thermoregulator, Adjustable Type. The regulator element shown in Figure 133 combines the advantages of the above-described elements with means for adjusting the range. The contact wire is carried by an armature which can be rotated by means of an externally located permanent magnet. The advantage of a completely sealed element is thereby retained.



Courtesy, Precision Thermometer and Instrument Co.

Figure 133. Adjustable Type of Precision Thermometer

This company also supplies appropriate relays for use with these elements in complete thermostat installations. Electronic type relays are also available.

Precision Thermoregulators, Fixed Type. These regulator elements, in a variety of forms shown in Figure 134, are widely used, especially for temperature control in the crystal ovens of radio broadcasting equipment. Seven million operations without impairment have repeatedly been recorded. The column is virtually nonseparable under vibration effects equivalent to 25 or 35 foot-pounds, or centrifugal force from the bulb equivalent to 100 grams. The accuracy tolerance is given as $\pm 0.05°$ C. with functional precision of 0.02° to 0.03° C.

Acknowledgments

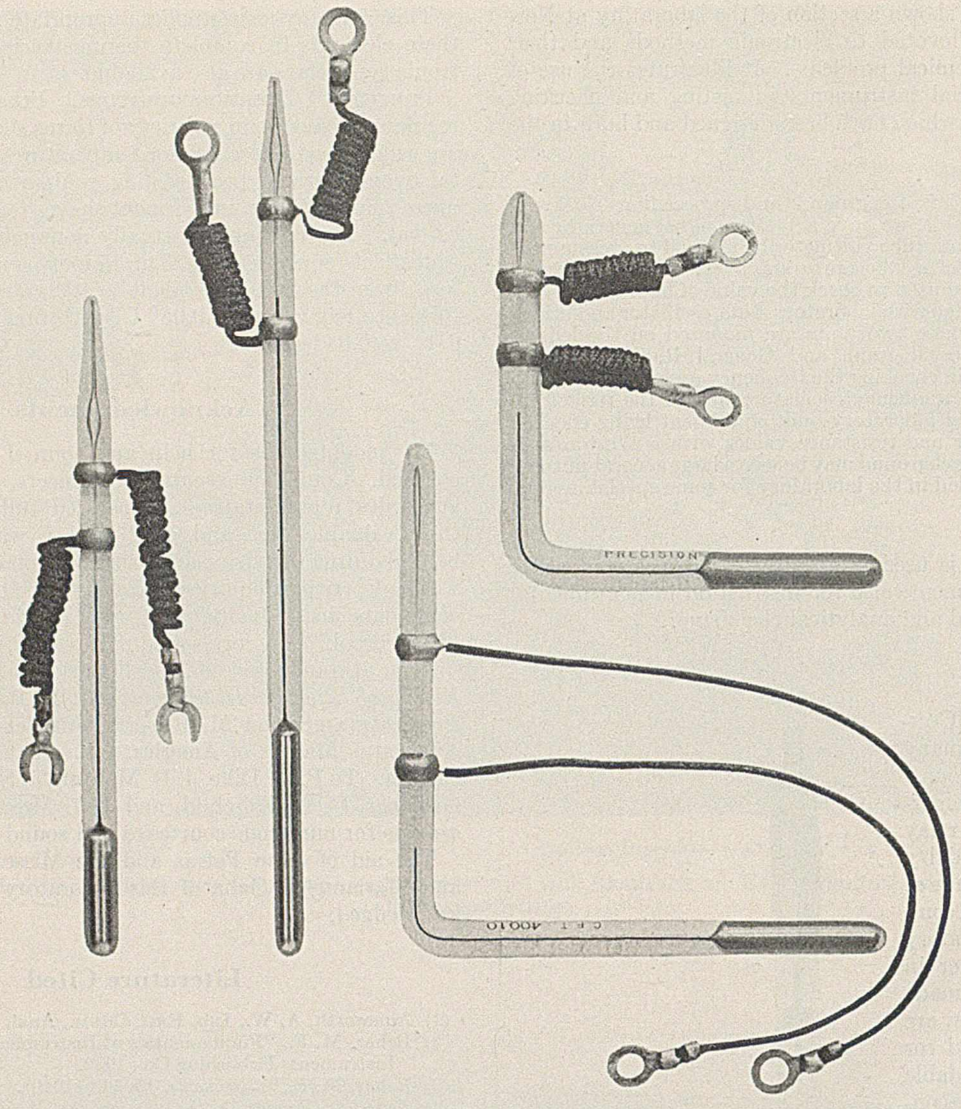
My indebtedness for help and counsel is not easily discharged. Company executives, engineers, research directors, and sales representatives cooperated fully, gave much of their valuable time and good advice, were courteous and helpful during my visits, and exhibited commendable patience with my written inquiries. Could they all have made their comments individually, this review would be a revised "Glazebrook" and correspondingly valuable.

I am also indebted to Joseph Becker, acting editor of the *Review of Scientific Instruments*, M. F. Behar, editor of *Instruments*, and John M. Roberts, president of the Scientific Apparatus Makers of America, for valuable advice and discussion. To P. H. Dike, J. B. McMahon, E. D. Haigler, Wm. Gaertner, C. O. Fairchild, and J. J. Moran especial thanks are due for numerous courtesies and sound advice.

The aid of John Petras and the Misses Evelyn Gamble and Marianne LaGana of this laboratory is gratefully acknowledged.

Literature Cited

(1) Ainsworth, A. W., Ind. Eng. Chem., Anal. Ed., **11**, 572 (1939).
(2) Behar, M. F., "Fundamentals of Instrumentation", Pittsburgh, Instruments Publishing Co., 1932.
(3) Behar, M. F., *Instruments*, **13**, 113 (1940).
(4) Benedetti-Pichler, A. A., and Spikes, W. F., "Introduction to the Microtechnique of Inorganic Qualitative Analysis", Douglaston, N. Y., Microchemical Service, 1935.
(5) Chamot, É. M., and Mason, C. W., "Handbook of Chemical Microscopy", New York, John Wiley & Sons, 1940.
(6) Clark, W. R., *Trans. Am. Inst. Elec. Engrs.*, **59**, 1 (1940).
(7) Clarke, B. L., and Hermance, H. W., *Bell System Tech. J.*, **15**, 483 (1936).
(8) Clarke, B. L., and Hermance, H. W., Ind. Eng. Chem., Anal. Ed., **7**, 218 (1935); **9**, 292 (1937); **10**, 591 (1938).
(9) Daynes, H. A., "Gas Analysis by Measurement of Thermal Conductivity", New York and London, Cambridge University Press, 1933.
(10) Fairchild, C. O., and Parsegian, V. L., *Rev. Sci. Instruments*, **9**, 422 (1938).
(11) Geddes, N. B., "Magic Motorways", New York, Random House, American Book-Stratford Press, 1940.
(12) Gibson, K. S., Natl. Bur. Standards, *Letter Circ.* LC-545, (March 8, 1939).
(13) Gilbert, R. W., *Rev. Sci. Instruments*, **7**, 41 (1936).
(14) Haigler, E. D., *Trans. Am. Soc. Mech. Engrs.*, **59**, 633 (1937).
(15) Hansen, C. A., Jr., *Gen. Elec. Rev.*, **43**, 166 (1940).
(16) Hardy, A. C., and Perrin, F. H., "Principles of Optics", Chap. XIX, New York, McGraw-Hill Book Co., 1932.
(17) Hennessy, D. J., and Cerecedo, L. R., *J. Am. Chem. Soc.*, **61**, 179 (1939).
(18) Jacobsohn, S., and Kliever, W. H., *J. Optical Soc. Am.*, **25**, 244 (1935).
(19) Knorr, H. V., and Albers, V. M., *Rev. Sci. Instruments*, **8**, 183 (1937).
(20) Lindeck, St., and Rothe, *Z. Instrumentenk.*, **20**, 293 (1900).
(21) Lundell, G. E. F., private communication.
(22) McCauley, G. V., *Sci. Monthly*, **34**, 79 (1934).
(23) McFarlan, R. L., Reddie, J. W., and Merrill, E. C., Ind. Eng. Chem., Anal. Ed., **9**, 324 (1937).
(24) Machler, R. C., *Rev. Sci. Instruments*, **10**, 386 (1939).



Courtesy, Precision Thermometer and Instrument Co.

FIGURE 134. PRECISION THERMOREGULATORS OF FIXED TYPE

(25) Machler, R. C., "7th Summer Conference on Spectroscopy and Its Applications", Cambridge, Mass., M. I. T. Technical Press, 1940.
(26) McMahon, J. B., IND. ENG. CHEM., 29, 1219 (1937).
(27) Mason, C. E., *Trans. Am. Soc. Mech. Engrs.*, 60, 327 (1938).
(28) Mason, C. E., and Philbrick, G. A., *Ibid.*, 61, 1 (1939).
(29) Müller, R. H., IND. ENG. CHEM., Anal. Ed., 11, 1 (1939).
(30) Müller, R. H., Garman, R. L., Droz, M. E., and Petras, J. F., *Ibid.*, 10, 339 (1938).
(31) Munz, E., and Brabender, C. W., *Cereal Chem.*, 17, 78 (1940).
(32) Natl. Bur. Standards, *Misc. Publ.* M160 (1937).
(33) Natl. Bur. Standards, *Research Papers* 506, 1194, 1195.
(34) Niederl, J. B., and Niederl, V., "Micromethods of Quantitative Organic Elementary Analysis", New York, John Wiley & Sons, 1938.
(35) Rhodes, E. O., *Proc. Am. Soc. Testing Materials*, 38, 551 (1938).
(36) Saxl, E. J., IND. ENG. CHEM., 30, 82 (1938).
(37) Saxl, E. J., *Rayon Textile Monthly*, p. 3 (Feb., 1938).
(38) Saxl, I. J., *J. Textile Inst.*, 26, T77 (1935).
(39) Saxl, I. J., *Rev. Sci. Instruments*, 5, 365 (1934).
(40) Saxl, I. J., *Ibid.*, 7, 429 (1936).
(41) Saxl, I. J., *Textile Research*, 5, 519 (1935); 8, 5–14 (1937).
(42) Secretary of Commerce, U. S. Dept. Commerce, Ann. Rpt., 1939.
(43) Sisson, W. A., and Clark, G. L., IND. ENG. CHEM., Anal. Ed., 5, 296 (1933).
(44) Strong, John, *Ibid.*, 11, 567 (1939).
(45) Strong, John, "Procedures in Experimental Physics", New York, Prentice-Hall, 1938.
(46) Sullivan, H. M., IND. ENG. CHEM., Anal. Ed., 8, 382 (1936).
(47) Teague, W. D., "Design This Day", New York, Harcourt, Brace and Co., 1940.
(48) Van Doren, Harold, "Industrial Design", New York, McGraw-Hill Book Co., 1940.
(49) Wells, W. F., Phelps, E. B., and Winslow, C. E. A., Am. Public Health Assoc. Year Book, p. 97, 1936–37.
(50) Williams, A. J., Jr., *Trans. Am. Inst. Elec. Engrs.*, 57, 1 (1938).

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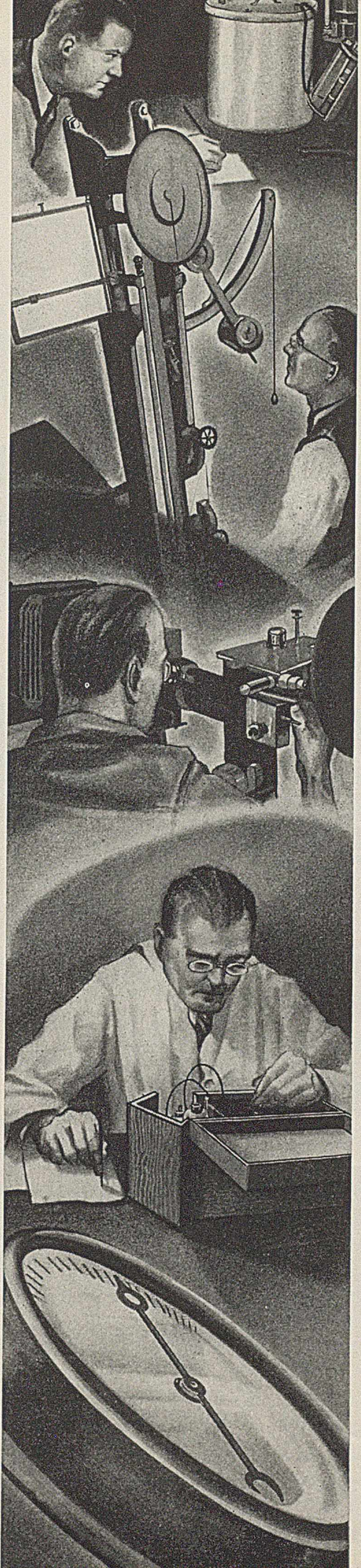


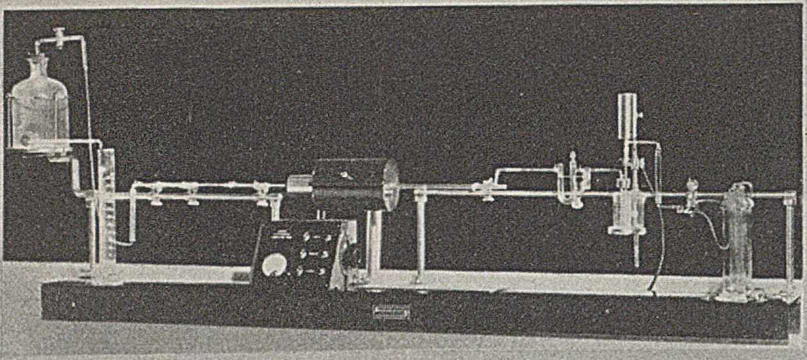
A Directory of Instruments and Related Apparatus

ANALYTICAL EDITION OF INDUSTRIAL AND ENGINEERING CHEMISTRY

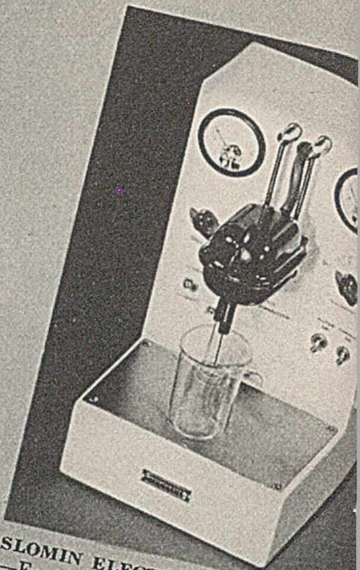
OCTOBER, 1940

Examples of Modern Instrumentation

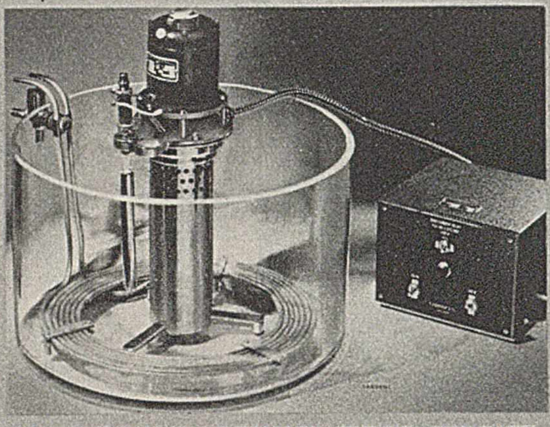
SARGENT FURNACE FOR MICRO COMBUSTION TRAINS—Can be placed in or removed from trains without removing combustion tube. Furnace shell is all steel and base of cast metal. Refractories interchangeable and replaceable. Pyrometer gives temperature *inside* of combustion tube.



SARGENT MICRO CARBON-HYDROGEN COMBUSTION TRAIN—Accommodates all glassware of commonly employed combustion trains. Mortar thermostatically controlled and preset at 177°C. Furnace is rheostat controlled. Pyrometer indicates temperature *inside* of combustion tube. Operates from 110 volt 60 cycle circuits.



SLOMIN ELECTROLYTIC ANALYZE —For high speed analysis. Portabl Economical. Operates from standard ele tric circuits.

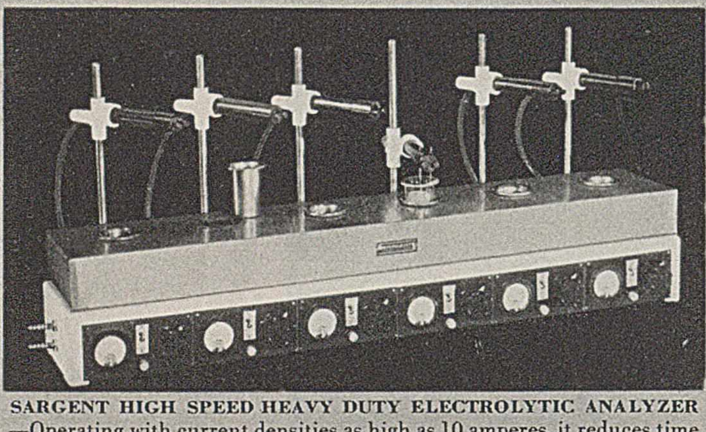


SARGENT CONSTANT TEMPERATURE WATER BATH —Guaranteed accuracy of regulation and uniformity, 0.01°C. Range, up to 60°C. Immersed objects fully visible through walls of container.

CAMERON GLASS ELECTRODE pH METER—Portable. Easy to operate. Permits rapid pH measurement. Accuracy, 0.1 pH unit. Complete meter, $79.50.

SARGENT CONE DRIVE STIRRING MOTOR—Silent. Vibrationless. Full motor power at all speeds. Range, 75 to 1300 r.p.m. Brushless, induction motor—safe in all environments.

SARGENT CONSTANT TEMPERATURE VISCOSIMETER BATH—Range, 0 to 210°F (98.9°C). Readings of pipettes made through transparent walls of container while pipettes are immersed. Accuracy of regulation and uniformity, 0.02°F.



SARGENT HIGH SPEED HEAVY DUTY ELECTROLYTIC ANALYZER —Operating with current densities as high as 10 amperes, it reduces time formerly required for deposition by as much as 60%. Electrolyte agitated electromagnetically—mechanical, stirring mechanisms eliminated.

HEYROVSKY IMPROVED MODEL MICRO POLAROGRAPH—Photographi recording. Applied to single or serial identi fication and determiation of ions capable of reduction at a dropping mercury cathode and also many anions.

COMPLETE INFORMATION ON REQUEST

SARGENT

LABORATORY SUPPLIES

E. H. Sargent & Co. · 155-165 East Superior St., Chicago

Names and Addresses of Firms Listed in the Instrument Index

Index starts on page 27

A

Accurate Pyrometric Cone Co., Pataskala, Ohio
Ace Glass, Inc., Vineland, N. J.
Ainsworth & Sons, Wm., 2151 Lawrence St., Denver, Col.
Akatos, Inc., 55 Van Dam St., New York, N. Y.
Alberene Stone Corp. of Va., 419 Fourth Avenue, New York, N. Y.
Allied Control Co., Inc., 227 Fulton Street, New York, N. Y.
Alsop Engineering Corp., 1739 Main Street, Milldale, Conn.
American Gas Furnace Co., Spring & Lafayette Sts., Elizabeth, N. J.
American Instrument Co., 8010 Georgia Ave., Silver Spring, Md.
American Meter Co., 60 East 42nd St., New York, N. Y.
American Paulin System, 1847 So. Flower St., Los Angeles, Calif.
American Platinum Works, N. J. R. R. Ave. at Oliver St., Newark, N. J.
American Seitz Filter Corp., 204–208 21st St., Paterson, N. J.
American Transformer Co., 175 Emmet St., Newark, N. J.
Ames Co., B. C. Waltham, Mass.
Amthor Testing Instrument Co., Inc., 309 Johnson St., Brooklyn, N. Y.
Angel & Co., Inc., H. Reeve, 75 Spruce St., New York, N. Y.
Applied Research Labs., 1208 San Julian St., Los Angeles, Calif.
Arca Regulators, Inc., 109 Tichenor St., Newark, N. J.
Askania Regulator Co., 1603 So. Michigan Ave., Chicago Ill.
Atlas Car & Mfg. Co., 1120 Ivanhoe Rd., Cleveland, Ohio
Atlas Electric Devices Co., 361 W. Superior St., Chicago, Ill.
Automatic Electric Co., 1033 W. Van Buren St., Chicago, Ill.
Automatic Electric Mfg. Co., Mankato, Minn.
Automatic Switch Co., 41 E. 11th St., New York, N. Y.
Automatic Temperature Control Co., 34 E. Logan St., Philadelphia, Pa.

B

Bacharach & Co., E. W., Rialto Bldg., Kansas City, Mo.
Bacharach Industrial Instrument Co., 7000 Bennett St., Pittsburgh, Pa.
Bailey Meter Co., 1050 Ivanhoe Rd., Cleveland, Ohio
Baldwin-Southwark Corp., Eddystone, Pa.
Barber-Coleman Co., 150 Loomis St., Rockford, Ill.
Bausch & Lomb Optical Co., 609 St. Paul St., Rochester, N. Y.
Becker, Inc., Christian, 92 Reade St., New York, N. Y.
Becker, Joseph, 630 W. 168th St., New York, N. Y.
Betts & Betts Corp., 551 W. 52nd St., New York, N. Y.
Bin-Dicator Co., 14615 E. Jefferson Ave., Detroit, Mich.
Bishop & Co. Platinum Works, J., 22 Channing Avenue, Malvern, Pa.
Black-Ray Lighting Co., 10415 St. Clair Ave., Cleveland, Ohio
Boiler Room Equipment, Inc., 45 W. 45th St., New York, N. Y.
Boulin Instrument Corp., 65 Madison Ave., New York, N. Y.
Bowser & Co., Inc., S. F., 1360 Creighton Ave., Fort Wayne, Ind.
Brabender Corp., Rochelle Park, N. J.
Braun Corp., 2260 E. 15th St., Los Angeles, Calif.
Braun-Knecht-Heimann Co., 584 Mission St., San Francisco, Calif.
Bristol Co., Waterbury, Conn.
Brookfield Engineering Laboratories, Sharon, Mass.
Brosites Machine Co., 30 Church Street, New York, N. Y.
Brown Instrument Co., 4480 Wayne Ave., Philadelphia, Pa.
Brown & Sharpe Mfg. Co., 237 Promenade St., Providence, R. I.
Brush Development Co., 3311 Perkins Ave., Cleveland, Ohio
Buehler, Adolph I., 228 N. LaSalle St., Chicago, Ill.
Buffalo Apparatus Corp., 180 Main St., Buffalo, N. Y.
Buffalo Meter Co., 2899 Main St., Buffalo, N. Y.
Builders Iron Foundry, 27 Codding St., Providence, R. I.
Bullard Co., E. D., 275 Eighth St., San Francisco, Calif.
Bunnell and Co., J. H., 215 Fulton St., New York, N. Y.
Burling Instrument Co., 241 Springfield Ave., Newark, N. J.
Burlington Instrument Corp., Burlington, Iowa
Burrell Technical Supply Co., 1942 Fifth Ave., Pittsburgh, Pa.
Bushnell & Nevius, 913 N. La Cienega Blvd., Los Angeles, Calif.

C

Calculagraph Co., 50 Church St., New York, N. Y.
Cambridge Instrument Co., Inc., 3732 Grand Central Terminal, New York, N. Y.
Cargille, R. P., 118 Liberty St., New York, N. Y.
Cash Co., A. W., 19th & Eldorado, Decatur, Ill.
Central Scientific Co., 1700 Irving Park Blvd., Chicago, Ill.
Chemical Rubber Co., 1900 W. 112th St., Cleveland, Ohio
Chemlab Specialties Co., 52 Alvarado Rd., Berkely, Calif.
Chicago Apparatus Co., 1735 N. Ashland Ave., Chicago, Ill.
Claflin Co., G. L., 150 Dorrance St., Providence, R. I.
Clare & Co., C. P., Lawrence & Lamson Avenues, Chicago, Ill.
Clark Blast Meter, Chas J., Gladbrook, Iowa
Clay-Adams Co., Inc., 44 E. 23rd St., New York, N. Y.
Clebar Watch Co., Inc., 551 Fifth Ave., New York, N. Y.
Clough-Brengle Co., 5501 Broadway, Chicago, Ill.
Cochrane Corp., 3125 N. 17th St., Philadelphia, Pa.
Coleman Electric Co., Inc., 315 Madison St., Maywood, Ill.
Colloid Equipment Co., 50 Church St., New York, N. Y.
Connelly Iron Sponge & Governor Co., 3154 S. California Ave., Chicago, Ill.
Continental Electric Co., Geneva, Ill.
Coors Porcelain Co., Golden, Colorado.
Corning Glass Works, Corning, N. Y.
Cramer & Co., R. W., Centerbrook, Conn.
Crosby Steam Gage & Valve Co., 10 Roland St., Boston, Mass.

D

Daigger & Co., A., 159 W. Kinzie St., Chicago, Ill.
Davis Emergency Equipment Co., Inc., 57 Van Dam St., New York, N. Y.
Defender Automatic Reg. Co., 308 S. 8th St., St. Louis, Mo.
Denver Fire Clay Co., 23d & Blake St., Denver, Colo.
Detroit Air Meter Co., P. O. Box 1473, Detroit, Mich.
Dietert Co., Harry W., 9330 Roselawn Ave., Detroit, Mich.
Distillation Products, Inc., 785 Ridge Road West, Rochester, N. Y.
Dubrovin, John, 2947 N. Kenneth Ave., Chicago, Ill.
DuMont Labs., Inc., Allen B., 2 Main St., Passaic, N. J.
Dunn, Inc., Struthers, 1328 Cherry St., Philadelphia, Pa.

E

Eagle Signal Corp., 20th St., Moline, Ill.
Eastern Engineering Co., 45 Fox St., New Haven, Conn.
Eberbach & Sons, 200 E. Liberty St., Ann Arbor, Mich.
Eby, Inc., Hugh H., 4700 Stenton Avenue, Philadelphia, Pa.
Eck & Krebs, 131 West 24th St., New York, N. Y.
Eclipse Fuel Engineering Co., Rockford, Ill.
Edison Electrical Controls Div., Thos. A. Edison, Inc., 51 Lakeside Ave., West Orange, N. J.
Eimer & Amend, 205–223 Third Ave., New York, N. Y.
Electric Speed Indicator Co., 14618 Bayes Ave., Lakewood, Ohio
Electric Tachometer Corp., Broad and Spring Garden Sts., Philadelphia, Pa.
Electric Valve Mfg. Co., 68 Murray St., New York, N. Y.
Electrical Research Products, Inc., 195 Broadway, New York, N. Y.
Electronic Laboratory, 306 S. Edinburgh Avenue, Los Angeles, Calif.
Electronic Research Lab., Niles Center, Ill.
Elgin Softener Corp., Elgin, Ill.
Empire Laboratory Supply Co., 559 W. 132nd St., New York, N. Y.
Engelhard, Inc., Charles, 90 Chestnut St., Newark, N. J.
Engineering Labs., Inc., 705 Kennedy Bldg., Tulsa, Okla.
Eppley Laboratory, Inc., Newport, R. I.
Ertel Engineering Co., 94 Mills Street, Kingston, N. Y.
Ess Instrument Co., 30 Irving Place, New York, N. Y.
Esterline-Angus Co., P. O. Box 596, Indianapolis, Ind.
Everson Mfg. Co., 210 W. Huron St., Chicago, Ill.
Exact Weight Scale Co., 1800 West Fifth Ave., Columbus, Ohio

F

Faichney Instrument Corp., Watertown, N. Y.
Fairbanks, Morse & Co., 600 S. Michigan Ave., Chicago, Ill.
Federal Products Corp., 1146 Eddy St., Providence, R. I.
Fee & Stemwedel, Inc., 4949 N. Pulaski Rd., Chicago, Ill.
Fenwal, Inc., Ashland, Mass.
Ferner Co., R. Y., 131 State St., Boston, Mass.
Ferranti Electric, Inc., 30 Rockefeller Plaza, New York, N. Y.
Ferris Instrument Corp., Boonton, N. J.
Fischer & Porter Co., 112 West Penn St., Germantown, Philadelphia, Pa.
Fish-Schurman Co., 254 E. 43rd St., New York, N. Y.
Fisher Scientific Co., 711–723 Forbes St., Pittsburgh, Pa.
Fleischhauer & Son, Frank, 89–36 187th Pl., Hollis, L. I., N. Y.
Ford Motor Co., 3674 Schaefer Road, Dearborn, Mich.
Foster Engineering Co., 109 Monroe St., Newark, N. J.
Foxboro Company, 40 Neponset Ave., Foxboro, Mass.
Friez & Sons, Julien P., Towson, Md.
Frober Faybor Co., 4612 Prospect Ave., Cleveland, Ohio
Fulton Sylphon Co., Knoxville, Tenn.

G

Gaertner Scientific Corp., 1201 Wrightwood Ave., Chicago, Ill.
Gardner Laboratory, Henry A., 2201 New York Ave., N.W., Washington, D. C.
Gauthier, Donat A., 7408 Poe Ave., Detroit, Mich.
General Electric Company, 1 River Rd., Schenectady, N. Y.
General Electric Vapor Lamp Co., 410 Eighth St., Hoboken, N. J.
General Electric X-Ray Corp., 2012 Jackson Blvd., Chicago, Ill.
General Radio Company, 30 State St., Cambridge, Mass.
Geophysical Instrument Co., 1315 Half St., S.E., Washington, D. C.
Gilmore Drug Co., W. J., 422 Blvd. of the Allies, Pittsburgh, Pa.
Gleason-Avery, Inc., 27 Clark St., Auburn, N. Y.
G-M Laboratories, Inc., 1731 W. Belmont Ave., Chicago, Ill.
Gordon Co., Claud S., 1524 S. Western Ave., Chicago, Ill.
Gorrell & Gorrell, Chicago Heights, Ill.

Gotham Instrument Co., 127 Spring St., New York, N. Y.
Gow-Mac Instrument Co., 20 Washington Pl., Newark, N. J.
Gray Instrument Co., 64½ W. Johnson St., Philadelphia, Pa.
Green, Henry J., 1191 Bedford Ave., Brooklyn, N. Y.
Greene Bros., Inc., 1810 Griffin St., Dallas, Texas
Greiner, Inc., Emil, 161 Sixth Ave., New York, N. Y.
Greiner Co. Inc., Otto R., 55 Plane St., Newark, N. J.
Guardian Electric Mfg. Co., 1621 W. Walnut St., Chicago, Ill.
Gump Co., B. F., 415 S. Clinton St., Chicago, Ill.
Gurley, W. & L. E., Troy, N. Y.

H

Hagan Corp., 300 Ross St., Pittsburgh, Pa.
Haines Gauge Co., 119 S. 4th St., Philadelphia, Pa.
Hanovia Chemical and Manufacturing Co., Chestnut St. & N.J.R.R. Ave., Newark, N. J.
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Hellige, Inc., 3718 Northern Blvd., Long Island City, N. Y.
Heusser Instrument Mfg. Co., 134 West Second South St., Salt Lake City, Utah
Hevi Duty Electric Co., 4214 West Highland Blvd., Chicago, Ill.
Hickok Electrical Instrument Co., 10514 Du Pont Ave., Cleveland, Ohio
Hoffman Co., S. O., 835 Howard St., San Francisco, Calif.
Hoke, Inc., 585 Eagle Ave., New York, N. Y.
Holz, Herman A., 116 W. 14th St., New York, N. Y.
Hopf Glass Apparatus Co., 192 3rd Avenue, New York, N. Y.
Hoskins Mfg. Co., 4455 Lawton Ave., Detroit, Mich.
Howe & French Inc., 101 Broad St., Boston, Mass.
Howe Scale Co., Rutland, Vt.
Huppert, K. H., 1603 S. Michigan Avenue, Chicago, Ill.

I

Ideal Commutator Dresser Co., Sycamore, Ill.
Illinois Testing Labs., 420 N. LaSalle St., Chicago, Ill.
Indicating Calipers Corp., 506 E. 19th St., New York, N. Y.
Industrial Instrument Co., 2249 14th St., S.W., Akron, Ohio
Industrial Instruments Inc., 156 Culver Ave., Jersey City, N. J.
Industro Scientific Co., 260 S. Broad St., Philadelphia, Pa.
Intercontinental Marketing Corp., 8 W. 40th St., New York, N. Y.
International Emulsifiers, Inc., 2409 Surrey Court, Chicago, Ill.
International Equipment Co., 352 Western Ave., Boston, Mass.
International Filter Co., 325 W. 25th Pl., Chicago, Ill.

J

J.B.T. Instruments Inc., 441 Chapel St., New Haven, Conn.
Jarrell-Ash Co., 165 Newbury St., Boston, Mass.
Jardur Import Co., 21 W. 19th St., New York, N. Y.
Jerguson Gage & Valve Co., 91 Fellsway Ave., Somerville, Mass.
Jones Motrola Sales Co., 432 Fairfield Ave., Stamford, Conn.

K

Kauffman-Lattimer Co., Columbus, Ohio
Keller Mfg. Co., G. P., Salt Lake City, Utah
Kessling Thermometer Co., E., 682 Jamaica Ave., Brooklyn, N. Y.
Keuffel & Esser Co., 300 Adams St., Hoboken, N. J.
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Kieley & Mueller, Inc., 40 W. 13th St., New York, N. Y.
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King-Seeley Corp., Detroit Ave., Ann Arbor, Mich.
Klett Mfg. Co., 179 E. 87th St., New York, N. Y.
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Kron Co., 1720 Fairfield Ave., Bridgeport, Conn.
Kurman Electric Co., Inc., 241 Lafayette St., New York, N. Y.

L

L. A. B. Corporation, Summit, N. J.
Laboratory Construction Co., Inc., 1113 Holmes Street, Kansas City, Missouri
Laboratory Furnitue Company, 37–18 Northern Boulevard, Long Island City, N. Y.
LaMotte Chemical Products Co., Towson, Baltimore Md.
LaPine & Co., Arthur S., 114 W. Hubbard St., Chicago, Ill.
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Leach Relay Co., 5915 Avalon Blvd., Los Angeles, Calif.
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Liquidometer Co., Inc., 36–18 Skillman Ave., Long Island City, N. Y.
Luxtrol Co., Inc., 54 West 21st St., New York, N. Y.

M

Macbeth Daylighting Co., Inc., 227 W. 17th St., New York, N. Y.
Machlett & Son, E., 220 E. 23rd St., New York, N. Y.
Manning, Maxwell & Moore, Inc., American Schaeffer & Budenberg Instrument Div., Bridgeport, Conn.
Marsh Corp., Jas. P., 2073 Southport Ave., Chicago, Ill.
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McKesson - Robbins - Doster - Northington Co., 1706 First Ave., Birmingham, Ala.
Mercoid Corp., 4201 W. Belmont St., Chicago, Ill.
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Meriam Co., 1955 W. 112th St., Cleveland, Ohio
Merrick Scale Mfg. Co., 188 Autumn St., Passaic, N. J.
Meylan, A. R. & J. E., 264–68 W. 40th St., New York, N. Y.
Mico Instrument Co., 10 Arrow St., Cambridge, Mass.
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Micro Switch Corp., Freeport, Ill.
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Moeller Instrument Co., 132–12—89th Ave., Richmond Hill, N. Y.
Morehouse Machine Co., 233 W. Market St., York, Pa.
Morey & Jones, Ltd., 922 So. Hemlock St., Los Angeles, Calif.
Muter Co., 1255 S. Michigan Ave., Chicago, Ill.

N

National Meter Co., 4213 First Ave., Brooklyn, N. Y.
National Technical Labs., 3330 East Colorado St., Pasadena, Calif.
Natural Gas Equipment, Inc., Petroleum Securities Bldg., Los Angeles, Calif.
Newark Scale Works, 10 Hobson St., Newark, N. J.
Newark Wire Cloth Co., 352 Verona Ave., Newark, N. J.
N. J. Laboratory Supply Co., 235 Plane St., Newark, N. J.
New Jersey Meter Co., Plainfield, N. J.
N. Y. Laboratory Supply Co., Inc., 525 Broadway, New York, N. Y.
New York Scientific Supply Co., 111 E. 22nd St., New York, N. Y.

O

Ohmite Mfg. Co., 4835 Flournoy Street, Chicago, Ill.
Olsen Testing Machine Co., Tinius, 500 N. 12th St., Philadelphia, Pa.
Orton Jr. Ceramic Foundation, Edward, 1445 Summit St., Columbus, Ohio

P

Palmer Company, 2501 Norwood Ave., Cincinnati, Ohio
Palo-Myers, Inc., 81 Reade St., New York, N. Y.
Parks-Cramer Co., 1101 Old South Bldg., Boston, Mass.
Parr Instrument Co., 222—52nd St., Moline, Ill.
Partlow Corp., 2 Campion Road, New Hartford, N. Y.
Pecorella Mfg. Co., 64 Stanhope St., Brooklyn, N. Y.
Perkin, Elmer & Moffitt, 90 Broad St., New York, N. Y.
Perkins & Son, Inc., B. F., Holyoke, Mass.

Permutit Co., 330 W. 42nd St., New York, N. Y.
Peterson & Co., Inc., Leonard, 1222 Fullerton Avenue, Chicago, Ill.
Petrometer Corp., 42-26—28th St., Long Island City, N. Y.
Pfaltz & Bauer, Inc., Empire State Bldg., New York, N. Y.
Philadelphia Thermometer Co., 915 Filbert St., Philadelphia, Pa.
Photobell Corp., 123 Liberty St., New York, N. Y.
Photoswitch, Inc., 21 Chestnut St., Cambridge, Mass.
Photovolt Corp., 10 E. 40th St., New York, N. Y.
Pioneer Instrument Division of Bendix Aviation Corp., Bendix, N. J.
Pittsburgh Equitable Meter Co., 400 N. Lexington Ave., Pittsburgh, Pa.
Pittsburgh Instrument & Machine Co., 1026 Reedsdale St., Pittsburgh, Pa.
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Powers Regulator Co., 2726 Greenview Ave., Chicago, Ill.
Pratt & Whitney, Division Niles-Bement-Pond Co., 430 Capitol Ave., Hartford, Conn.
Precision Scientific Co., 1750 N. Springfield Ave., Chicago, Ill.
Precision Thermometer & Instrument Co., 1434 Brandywine St., Philadelphia, Pa.
Pyro-Electro Instrument Co., 7323 W. Chicago Blvd., Detroit, Mich.
Pyrometer Instrument Co., 103 Lafayette St., New York, N. Y.

R

Radio City Products Co., 88 Park Pl., New York, N. Y.
Rawson Electrical Instrument Co., 110 Potter St., Cambridge, Mass.
Raytheon Mfg. Co., 190 Willow St., Waltham, Mass.
RCA Manufacturing Co., Inc., Camden, N. J.
Refinery Supply Company, 621 E. Fourth St., Tulsa, Okla.
Republic Flow Meters Co., 2246 Diversey Parkway, Chicago, Ill.
Rex Rheostat Co., 37 W. 20th Street, New York, N. Y.
Rhoades Metaline Co., Inc., R. W., P. O. Box 1, Long Island City, L. I.
Richardson Scale Co., 668 Van Houten Ave., Clifton, N. J.
Riehle Testing Machine Div., American Machine & Metals, Inc., East Moline, Ill.
Robertshaw Thermostat Co., Youngwood, Pa.
Roller-Smith Co., Bethlehem, Pa.
Rubicon Co., 29 N. Sixth St., Philadelphia, Pa.
Ruehfel Company, George, 103 Monahan Street, Booklyn, N. Y.

S

Sarco Company, Inc., 183 Madison Ave., New York, N. Y.
Sargent & Co., E. H., 155 East Superior St., Chicago, Ill.
Saxl Instrument Co., Industrial Trust Bldg., Providence, R. I.
Schaffer Poidometer Co., 2828 Smallman St., Pittsburgh, Pa.
Scharr & Co., 754 W. Lexington St., Chicago, Ill.
Scherr Co., Inc., George, 128 Lafayette St., New York, N. Y.
Schutte & Koerting Co., 1261 N. 12th St., Philadelphia, Pa.
Scientific Glass Apparatus Co., 49 W. Ackerman St., Bloomfield, N. J.
Scientific Instrument Co., 535 W. Larned St., Detroit, Mich.
Scott Co., Henry L., Blackstone St., Providence, R. I.
Seederer-Kohlbusch, Inc., 149 New York Ave., Jersey City, N. J.
Selas Company, 18th St. & Indiana Ave., Philadelphia, Pa.
Service Recorder Co., 468 Hanna Bldg., Cleveland, Ohio
Sheffield Gage Corp., Dayton, Ohio
Sheldon & Co., E. H., Muskegon, Michigan
Shore Instrument & Mfg. Co., 90-25 Van Wyck Blvd., Jamaica, N. Y.
Sigma Instruments, Inc., 388 Trapelo Rd., Belmont, Mass.
Sola Electric Co., 2525 Clybron Street, Chicago, Ill.
Sound Apparatus Co., 150 West 46th Street, New York, N. Y.
Sparkler Mfg. Co., 1202 Webster Avenue, Chicago, Ill.
Specialty Glass Co., 536 Lake Shore Drive, Chicago, Ill.
Spence Engineering Co., Inc., 51 Grant St., Walden, N. Y.
Spencer Lens Co., 19 Doat St., Buffalo, N. Y.
Spray Engineering Co., 110 Central St., Somerville, Mass.
Standard Electric Time Co., 89 Logan St., Springfield, Mass.
Standard Electrical Products Co., 317 Sibley St., St. Paul, Minn.
Starrett Co., L. S., Athol, Mass.
Sta-Warm Electric Co., 860 N. Chestnut Street, Ravenna, Ohio
Sterling Engineering Co., 3738 N. Holton St., Milwaukee, Wis.
Sticht & Co., Herman H., 27 Park Place, New York, N. Y.
Stillman Co., M. J., 116 So. Michigan Ave., Chicago, Ill.
Stokes Machine Co., F. J., 5944 Tabor Rd., Olney, P. O., Philadelphia, Pa.
Supreme Electric Products Corp., 99 Mt. Hope Ave., Rochester, N. Y.
Supreme Instrument Corp., Greenwood, Miss.
Suter, Alfred, 200 Fifth Ave., New York, N. Y.

T

Taber Instrument Co., 111 Goundry St., North Tonawanda, N. Y.
Tagliabue Mfg Co., Park & Nostrand Aves., Brooklyn, N. Y.
Taylor & Co., Inc., W. A., 877 Linden Ave., Baltimore, Md.
Taylor Instrument Cos., 95 Ames St., Rochester, N. Y.
Tefft-Jackson, Inc., 2 Allens Ave., Providence, R. I.
Teliviso Products, Inc., 2400 N. Sheffield Blvd., Chicago, Ill.
Telex Products Co., Minneapolis, Minn.
Testing Machines, Inc., 460 W. 34th St., New York, N. Y.
Thermal Syndicate, Ltd., 12 East 46th Street, New York, N. Y.
Thomas Co., Arthur H., W. Washington Sq., Philadelphia, Pa.
Thompson Clock Co., H. C., Bristol, Conn.
Thordarson Electric Mfg. Co., 500 W. Huron St., Chicago, Ill.
Thrush & Co., H. A., Peru, Ind.
Thwing-Albert Instrument Co., 3339 Lancaster Ave., Philadelphia, Pa.
Toledo Scale Co., 3230 Monroe St., Toledo, Ohio
Torsion Balance Co., 92 Reade St., New York, N. Y.
Trill Indicator Co., 346 E. South St., Corry, Pa.
Trimount Instrument, Inc., 332 S. LaSalle Street, Chicago, Ill.
Triplett Electrical Instrument Co., Bluffton, Ohio
Troemner, Henry, 911 Arch St., Philadelphia, Pa.
Tyler Co., W. S., 3614 Superior Ave., Cleveland, Ohio

U

Uehling Instrument Co., 477 Getty Ave., Paterson, N. J.

V

Veeder-Root, Inc., Hartford, Conn.
Viking Instruments, Inc., Stamford, Conn.
Voland & Sons, Inc., New Rochelle, N. Y.

W

Walker & Co., G. T., 324—5th Ave., S., Minneapolis, Minn.
Walser Automatic Timer Co., 420 Lexington Ave., New York, N. Y.
Ward Leonard Electric Co., 31 South St., Mount Vernon, N. Y.
Welch Mfg. Co., W. M., 1518 Sedgwick St., Chicago, Ill.
Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.
Weston Electrical Instrument Corp., 614 Frelinghuysen Ave., Newark, N. J.
Wheelco Instrument Co., 1929 S. Halsted St., Chicago, Ill.
Wilkens-Anderson Co., 111 N. Canal St., Chicago, Ill.
Will Corp., Rochester, N. Y.
Williams Apparatus Co., Inc., Herald Bldg., Watertown, N. Y.
Williams Brown & Earle Inc., 918 Chestnut St., Philadelphia, Pa.
Willson Products, Inc., Reading, Pa.
Wilson Mechanical Inst. Co., 383 Concord Ave., New York, N. Y.

Y

Yonkers Lab. Supply Co., 549 W. 132 St., New York, N. Y.

Z

Zeiss, Inc., Carl, 485 Fifth Ave., New York, N. Y.

Index of Instruments

Related Apparatus and Machines

for Measuring, Testing, Controlling, Indicating and Recording

The information in this index is based on data furnished by the firms listed as well as from data taken from our own files. With exception of GAGES all index headings have been made on the basis of the subject or condition of measurement and control. For example, equipment for testing rubber and milk is found under RUBBER TESTING, and MILK TESTING, respectively.

Frequent cross references have been made to eliminate duplication of firm listings. For example—BENDING TESTING, See Tensile Testing, shows that firms which supply the former are identical with the firms supplying the latter. This does not imply that the equipment is identical.

The more important laboratory instruments have been separately indexed as warranted by their importance. For example POTENTIOMETERS are separately listed and have not been cross-indexed to ELECTRICAL MEASURING.

Selected useful and necessary laboratory items will be found under "MISCELLANEOUS" placed at the end of the Index together with "LABORATORY FURNITURE."

Proprietary trade names have been used only where the trade has no other aptly descriptive designation for the device.

If the product or name for which you are searching is not found in the Index, please communicate with the Advertising Office, Industrial and Engineering Chemistry, 332 West 42nd St., New York.

All suggestions for additional headings, as well as calling to our attention errors and discrepancies will be thoroughly appreciated.

For complete name and address of companies listed in this index consult page 21

A

ABRASION RESISTANCE
American Inst. Co.
Amthor Test Inst.
Morehouse Mach. Co.
Taber Inst. Co.

ABSORPTION, See Porosity

ACID HEAT
Tagliabue Mfg.

ALARMS
Noxious or Combustible Gases and Vapors
Bristol Co.
Bushnell and Nevins
Davis Emergency Engineering Labs., Inc.
Gen. Elec. Co.
Leeds & Northrup
Mine Safety
Viking Instruments
Wheelco Inst. Co.

ALCOHOL TESTING SETS
American Inst. Co.
Braun Corp.
Burrell Tech. Sup.
Central Scientific Co.
Daigger & Co., A.
Eimer & Amend
Fisher Scientific Co.
Greiner, Inc., Emil
Greiner & Co., Otto
La Pine & Co.
N. Y. Laboratory Sup.
Palo-Myers
Precision Scien. Co.
Sargent & Co., E. H.
Scientific Glass App.
Thomas Co., A. H.
Will Corp.

ALTERNATING STRESS, See Tensile Testing

AMMETERS, See Electrical Measuring

AMMONIA, ANALYZERS, See Gas Analyzers

AMPEREHOUR METERS, See Electrical and Magnetic Measuring

ANALYZERS
Chemical Composition, Recording and Controlling
Applied Res. Labs.
Cambridge Inst.
Coleman Electric
Dietert Co.
Fisher Scientific Co.
Friez and Sons
Industrial Insts., Inc.
Leeds & Northrup
Machlett and Son
Mine Safety
National Tech. Labs.
Rubicon Co.
Sargent and Co., E. H.
Scientific Glass App.
Tagliabue Mfg.

AREA METERS, See Flowmeters

ASPHALT TESTING
See Oil Testing

B

BALANCES, ANALYTICAL
Ainsworth & Sons
Akatos, Inc.
American Inst. Co.
Becker, Christian
Braun Corp.
Burrell Tech. Sup.
Central Scientific Co.
Claflin Co.
Clay-Adams Co., Inc.
Daigger & Co., A.
Eimer & Amend
Exact Weight Scale
Fisher Scientific Co.
Gaertner Scientific
Greiner, Inc., Emil
Greiner & Co., Otto
Jarrell-Ash Co.
Keller Mfg., G. P.
La Pine & Co.
Microchem. Service
N. Y. Laboratory Sup.
Palo-Myers
Sargent & Co., E. H.
Scientific Glass App.
Thomas Co., A. H.
Torsion Balance Co.
Troemner, Henry
Voland and Sons
Will Corp.

BALANCES, GAS DENSITY
Central Scientific Co.
Refinery Supply Co.

BALANCES, MICRO
Ainsworth and Sons
Akatos, Inc.
Becker, Christian
Central Scientific Co.
Heusser Instrument
Microchemical Service
Pfaltz & Bauer
Thomas Co., A. H.
Torsion Balance Co.
Voland and Sons

BALANCES, PULP
Ainsworth and Sons
Becker, Christian
Central Scientific Co.
Exact Weight Scale
Heusser Instrument
Seederer-Kohlbusch
Torsion Balance Co.
Troemner, Henry
Voland and Sons

BALANCES, SPECIFIC GRAVITY
Becker, Christian
Chicago App. Co.
Exact Weight Scale
Heusser Instrument
Newark Scale Works
Pfaltz & Bauer
Seederer-Kohlbusch
Torsion Balance Co.
Troemner, Henry

BALANCES, SURFACE TENSION
Becker, Christian
Central Scientific Co.
Roller-Smith Co.
Seederer-Kohlbusch
Torsion Balance Co.

BALANCES, WESTPHAL
Becker, Christian
Central Scientific Co.
Chicago App. Co.
Eimer and Amend
Pfaltz & Bauer
Seederer-Kohlbusch
Torsion Balance Co.
Troemner, Henry

BARKOMETERS, See Hydrometers

BAROMETERS
Braun Corp.
Burrell Tech. Sup.
Central Scientific Co.
Claflin Co.
Daigger & Co., A.
Eimer & Amend
Fisher Scientific Co.
Gaertner Scientific
Green, Henry J.
Greiner, Inc., Emil
Greiner & Co., Otto
La Pine & Co.
Manning, M. & M.
N. Y. Laboratory Sup.
Palo-Myers
Phila. Therm. Co.
Precision T. & I.
Sargent & Co., E. H.
Scientific Glass App.
Scientific Inst. Co.
Tagliabue Mfg.
Taylor Inst. Cos.
Thomas Co., A. H.
Uehling Inst. Co.
Will Corp.

BAROMETERS, ANEROID
Am. Paulin System
Central Scientific Co.
Friez and Sons
Keuffel and Esser Co.
Kollsman Inst. Co.
Pioneer Instrument Co.
Scientific Inst. Co.
Taylor Inst. Cos.

BAROMETERS, MERCURIAL
Central Scientific Co.
Chicago Apparatus Co.
Eimer and Amend
Fisher Scientific
Friez and Sons
Pioneer Instrument Co.
Sargent and Co., E. H
Scientific Inst. Co.
Specialty Glass Co.
Tagliabue Mfg. Co.
Taylor Inst. Cos.
Welch Mfg. Co.

BAROMETERS, RECORDING
Bristol Co.
Foxboro Co.
Friez and Sons
Keuffel and Esser
Taylor Inst. Cos.
Uehling Instrument

BENDING TESTING
See Tensile Testing

BOILING POINT
American Inst. Cos.
Braun Corp.
Burrell Tech. Sup.
Central Scientific Co.
Daigger & Co., A.
Eck & Krebs
Eimer & Amend
Fisher Scientific Co.
Greiner, Inc., Emil
Greiner & Co., Otto
La Pine & Co.
N. Y. Laboratory Sup.
Palo-Myers
Sargent & Co., E. H.
Scientific Glass App.
Thomas Co., A. H.
Will Corp.

BOLOMETERS, See Meteorological Measuring

BOMBS, COMBUSTION
American Inst. Co.
Central Scientific Co.
Parr Instrument Co.
Precision Scien. Co.
Tagliabue Mfg. Co.

BRICK TESTING
Morehouse Mach. Co.

BRIDGES, Electrical, See Potentiometers and Bridges

BRINELL HARDNESS
See Hardness Testing

B.T.U. INDICATORS
Precision Scien. Co.

BRITTLENESS, See Tensile Testing

BURNING TEST, See Oil Testing

BURSTING STRENGTH, See Paper Testing

Continued on Page 30

Now! A *Laboratory-Size*

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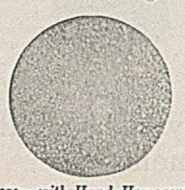
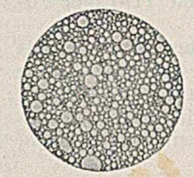
...Saves Time and Materials

For liquid batches of 1 to 10 oz Merely pour mixture into bow and press hand-lever. Homogenizes instantly—each stroke of hand-lever ejects a jet of completely emulsified liquid. Provides permanent suspension for emulsions—no failures, if ingredient ratio is sound. In photos at left, note fine degree of dispersion secured (above) compared to coarseness of same mixture emulsified with mortar and pestle (below).



Above—with Hand Homogenizer
Below—with mortar and pestle



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Dept. C4, 2409 Surrey Court, Chicago, Ill.

International
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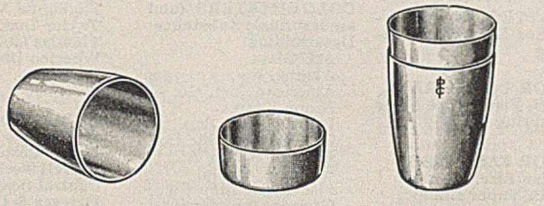

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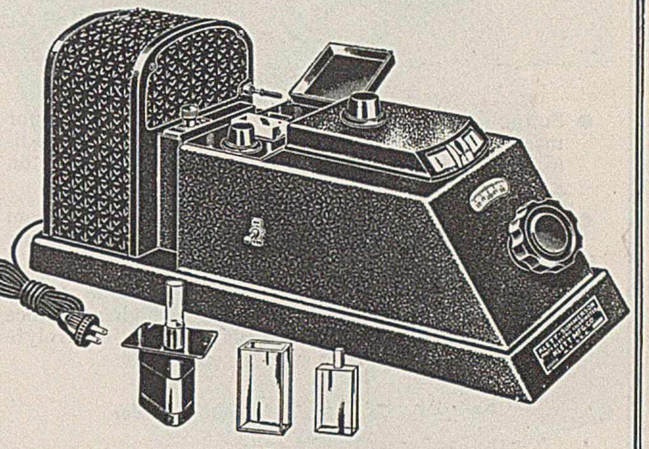
PARR INSTRUMENT COMPANY · Moline, Ill.

Klett-Summerson

PHOTOELECTRIC COLORIMETER

GLASS CELL MODEL



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Designed to meet the needs of industrial, agricultural, and commercial laboratories for a rugged, simple, and accurate photoelectric colorimeter.

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Write for detailed information

KLETT MANUFACTURING CO.
179 East 87th St. New York N. Y.

Continued from Page 27

C

CALIBRATING EQUIPMENT, for Testing Machines
Holtz, Herman A.
Pittsburgh Instrument
Saxl Instrument Co.
Thwing-Albert

CALIPERS, See Lineal Dimensions

CALORIMETERS
American Inst. Co.
Braun Corp.
Burrell Tech. Sup.
Central Scientific Co.
Daigger & Co., A.
Eimer & Amend
Faichney Inst. Corp.
Fisher Scientific Co.
Greiner, Inc., Emil
Greiner & Co., Otto
La Pine & Co.
N. Y. Laboratory Sup.
Palo-Myers
Parr Inst. Co.
Precision Scien. Co.
Precision T. & I.
Sargent & Co., E. H.
Scientific Glass App.
Thomas Co., A. H.
Will Corp.

CAPACITANCE, See Electrical Measuring

CARBON DIOXIDE See Gas Analyzers

CARBON MONOXIDE See Gas Analyzers

CARBON RESIDUE See Oil Testing

CATHETOMERS
Braun Corp.
Burrell Tech. Sup.
Central Scientific Co.
Daigger & Co., A.
Eimer & Amend
Fisher Scientific Co.
Gaertner Scien.
Greiner, Inc., Emil
Greiner & Co., Otto
La Pine & Co.
N. Y. Laboratory Sup.
Palo-Myers
Sargent & Co., E. H.
Scientific Glass App.
Thomas Co., A. H.
Will Corp.

CATHODE-RAY OSCILLOGRAPH
DuMont Lab.
General Electric Co.
General Radio Co.
Raytheon Mfg. Co.
RCA Mfg. Co.
Supreme Instruments
Telex Prod.
Triplett Electrical

CELLS, CONDUCTIVITY, ELECTRICAL
Cambridge Inst. Co.
Central Scientific Co.
Coleman Electric Co.
Fisher Scientific
Gray Instrument Co.
Industrial Insts., Inc.
Leeds and Northrup
Scientific Glass App.

CELLS, CONDUCTIVITY, THERMAL
Cambridge Inst. Co.
Central Scientific Co.
Gen. Elec. Co.
Gow-Mac Inst. Co.
Leeds and Northrup

CELLS, PHOTOELECTRIC
Continental Electric
Electronic Lab.
Gen. Elec. Co.
G-M Labs.
Hickok Elec. Inst.
Intercontinental
Luxtrol Co., Inc.
Pfaltz & Bauer
Photobell Corp.
Photovolt Corp.
RCA Mfg. Co.
Westinghouse E. & M.
Weston Elec. Inst.

CELLS, STANDARD
Cambridge Inst. Co.
Eppley Lab.
Leeds & Northrup
Rubicon Co.
Tagliabue Mfg. Co.
Thwing-Albert
Weston Elec. Inst.

CEMENT TESTING See also Tensile Testing
American Inst. Co.
Braun Corp.
Burrell Tech. Sup.
Central Scientific Co.
Daigger & Co., A.
Eimer & Amend
Fisher Scientific Co.
Greiner, Inc., Emil
Greiner & Co., Otto
La Pine & Co.
N. Y. Laboratory Sup.
Palo-Myers
Precision Scien. Co.
Sargent & Co., E. H.
Scientific Glass App.
Scientific Inst. Co.
Thomas Co., A. H.
Will Corp.

CENTRIFUGES
Clay-Adams Co.
Central Scientific Co.
Fisher Scientific
International Equip.
Precision Scientific
Tagliabue Mfg. Co.
Thomas Co., A. H.
Williams Apparatus

CHLORINE, See Gas Analyzers; See also Ortho-Tolidin Testing Sets

CHLORINE TESTING SETS
La Motte Chem. Prod.
Taylor & Co., W. A.

CHRONOGRAPHS See Time

CLOCKS, See Time

CLOUD AND POUR TEST, See Oil Testing

COAL AND COKE TESTING
American Inst. Co.
Precision Scien. Co.

COIL TESTING, Electric, See Electrical Measuring

COLOR COMPARATORS, Visual, See Color Measuring

COLOR FASTNESS
Atlas Elec. Dev.
G.E. Vapor Lamp

COLOR MEASURING See also Light Measuring
Ace Glass
Akatos, Inc.
American Inst. Co.
Black-Ray Light.
B. & L. Optical Co.
Braun Corp.
Buchler, A. I.
Burrell Tech. Sup.
Cargille, R. P.
Central Scientific Co.
Claflin Co.
Coleman Elec. Co.
Daigger & Co., A.
Eimer & Amend
Electronic Res. Lab.
Fish-Schurman
Fisher Scientific Co.
Gaertner Scien.
Gen. Elec. Co.
Greiner, Inc., Emil
Greiner & Co., Otto
Hellige, Inc.
Jarrell-Ash Co.
Kimble Glass
La Pine & Co.
Leitz, E.
Macbeth Daylight
N. Y. Laboratory Sup.
N. Y. Scientific Sup.
Palo-Myers
Pfaltz & Bauer
Photovolt Corp.
Precision Scien. Co.
Rubicon Co.
Sargent & Co., E. H.
Scientific Glass App.
Spencer Lens Co.
Tagliabue Mfg.
Thomas Co., A. H.
Wilkens-Anderson
Will Corp.
Zeiss, Inc., Carl

COLORIMETERS (and accessories) Substance Determining
Ace Glass
Akatos, Inc.
American Inst. Co.
Braun Corp.
Burrell Tech. Sup.
Central Scientific Co.
Daigger & Co., A.
Eimer & Amend
Fisher Scientific Co.
Greiner, Inc., Emil
Greiner & Co., Otto R.
Hellige, Inc.
Kimble Glass
Klett Mfg.
La Pine & Co.
N. Y. Laboratory Sup.
Palo-Myers
Pfaltz & Bauer
Sargent & Co., E. H.
Scientific Glass App.
Thomas Co., A. H.
Wilkens-Anderson
Will Corp.

COMBUSTION
Arca Regulators
Bacharach Ind. Inst.
Bailey Meter Co.
Bowser & Co.
Braun Corp.
Bristol Co.
Brown Inst. Co.
Burrell Tech. Sup.
Cash Co.
Central Scientific Co.
Daigger & Co., A.
Defender Auto. Reg.
Eimer & Amend
Ess Inst. Co.
Fisher Scientific Co.
Foxboro Co.
Gow-Mac Inst. Co.
Greiner, Inc., Emil
Greiner & Co., Otto
Hagan Corp.
Hays Corp.
La Pine & Co.
Leeds & Northrup
Mason-Neilan Reg.
N. Y. Laboratory Sup.
Palo-Myers
Permutit Co.
Repub. Flow Meters
Sargent & Co., E. H.
Scientific Glass App.
Spence Eng. Co.
Tagliabue Mfg.
Taylor Inst. Cos.
Thomas Co., A. H.
Wheelco Inst. Co.
Will Corp.

COMBUSTION Portable Sets
Braun Corp.
Burrell Tech. Sup.
Central Scientific Co.
Daigger & Co., A.
Eimer & Amend
Fisher Scientific Co.
Greiner, Inc., Emil
Greiner & Co., Otto
Hays Corp.
La Pine & Co.
N. Y. Laboratory Sup.
Palo-Myers
Precision Scien. Co.
Sargent & Co., E. H.
Scientific Glass App.
Thomas Co., A. H.
Will Corp.

COMPRESSION TESTING, See Tensile Testing

CONCRETE TESTING See Cement Testing

CONDENSER TESTING, See Electrical Measuring

CONDUCTIVITY, Electrical
Cambridge Inst. Co.
Coleman Elect. Co.
Esterline-Angus
Gen. Elec. Co.

For complete name and address of companies listed in this index consult page 21

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For complete name and address of companies listed in this index consult page 21

Scientific Inst. Co.
Tagliabue Mfg.
Taylor Inst. Cos.
Thomas Co., A. H.
Uehling Inst. Co.
Will Corp.

GAGES, Micrometer, See Lineal Dimensions

GAGES, Paint Film, See Paint Testing

GAGES, Precision, Measuring, See Lineal Dimensions

GAGES, Pressure, See Pressure and Vacuum

GAGES, Strain, See Tensile Testing

GAGES, Thickness, See Lineal Dimensions

GAGES, TORQUE
Riehle Div.
Saxl Inst.
Toledo Scale

GAGES, McLeod, See McLeod

GAGES, Vacuum, See Pressure and Vacuum

GAGES, Wire Measuring, See Lineal Dimensions

GALVANOMETERS See Electrical Measuring

GAS ANALYZERS
Ace Glass
American Inst. Co.
Bacharach & Co.
Braun Corp.
Brown Inst.
Bullard Co.
Burrell Tech. Sup.
Bushnell & Nevius
Cambridge Inst. Co.
Central Scientific Co.
Corning Glass Wks.
Daigger & Co., A.
Eimer & Amend
Engelhard, Inc.
Everson Mfg.
Fisher Scientific Co.
Foxboro Co.
Gen. Elect. Co.
Gow-Mac Inst. Co.
Greiner, Inc., Emil
Greiner & Co., Otto
Hays Corp.
La Pine & Co.
Leeds & Northrup
Linde Air
Machlett & Son
Mine Safety
N. Y. Laboratory Sup.
Palo-Myers
Permutit Co.
Precision Scien. Co.
Precision T. & I.
Republic Flow
Sargent & Co., E. H.
Scientific Glass App.
Scientific Inst. Co.
Tagliabue Mfg.
Taylor Inst. Cos.
Thomas Co., A. H.
Uehling Inst. Co.
Wheelco Inst. Co.
Will Corp.
Willson Products

GAS AND VAPOR DENSITY METERS, See Gas Analyzers; Gravitometers

GAS LEAK INDICATORS
Bushnell & Nevius
Davis Emerg. Equip.
Refinery Sup. Co.
Taylor Inst. Cos.

GAS METERS, See Flowmeters

GASOMETERS, See Gas Analyzers

GEOPHYSICAL MEASURING
American Inst. Co.
Cambridge Inst. Co.
Geophysical Inst. Co.

GLARE METERS, See Light Measuring

GLASS STRAIN TESTERS
Akatos, Inc.
Eimer & Amend
Gaertner Scient.
Gen. Elec. Co.
Leitz, E.
Polarizing Inst.
Zeiss, Inc., Carl

GLOSS METERS, See Light Measuring

GLUE TESTING
American Inst. Co.
Braun Corp.
Central Scientific Co.
Daigger & Co., A.
Eimer & Amend
Fisher Scientific Co.
Greiner, Inc., Emil
Greiner & Co., Otto
N. Y. Laboratory Sup.
Sargent & Co., E. H.
Scientific Glass App.
Thomas Co., A. H.
Will Corp.

GLUOMETERS, See Hydrometers

GONIOMETERS
Jarrell-Ash Co.
Zeiss, Inc., Carl

GRAIN TESTERS
American Inst. Co.
Braun Corp.
Burrell Tech. Sup.
Central Scientific Co.
Daigger & Co., A.
Eimer & Amend
Fisher Scientific Co.
Greiner, Inc., Emil
Greiner & Co., Otto
La Pine & Co.
N. Y. Laboratory Sup.
Palo-Myers
Sargent & Co., E. H.
Scientific Glass App.
Tagliabue Mfg.
Thomas Co., A. H.
Will Corp.

GRANULAR MATERIAL MEASURING, Volume-flow
Bailey Meter Co.
Bin-Dicator Co.
Gump Co.

GRATINGS, Diffraction, See Spectrometers

GRAVIMETERS, See Specific Gravity; Gravitometers

GRAVITOMETERS
Eimer & Amend
Permutit Co.
Precision T. & I.
Refinery Sup. Co.

GRAVITY INDICATORS AND RECORDERS, See Specific Gravity

GREASE TESTING See Oil Testing

GROUND RESISTANCE, See Electric Measuring

GUMMED TAPE TESTING, See Paper Testing

H

HARDNESS TESTING
American Inst. Co.
Braun Corp.
Burrell Tech. Sup.
Central Scientific Co.
Daigger & Co., A.
Dietert Co.
Eimer & Amend
Ferner Co.
Fisher Scientific Co.
Greiner, Inc., Emil
Greiner & Co., Otto
Holz, H. A.

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La Pine & Co.
N. Y. Laboratory Sup.
Olsen Test Mach.
Palo-Myers
Pgh. Inst. & Mach.
Pyro-Electro Inst.
Riehle Div.
Sargent & Co., E. H.
Saxl Inst.
Scientific Glass App.
Shore Inst. & Mfg.
Suter, A.
Test. Mach. Inc.
Thomas Co., A. H.
Will Corp.
Wilson Mech. Instr.

HARMONIC ANALYZERS, See Sound

HELIOSTATS, See Meteorological Measuring

HUMIDISTATS, See Humidity

HUMIDITY
American Inst. Co.
American Meter Co.
Braun Corp.
Bristol Co.
Brown Inst.
Bullard Co.
Burrell Tech. Sup.
Cambridge Inst. Co.
Central Scientific Co.
Daigger & Co., A.
Eimer & Amend
Engelhard, Inc.
Fee and Stemwedel
Fisher Scientific Co.
Foxboro Co.
Friez & Sons
Green, H. J.
Greiner, Inc., Emil
Greiner & Co., Otto
H-B Instrument Co.
La Pine & Co.
Leeds & Northrup
Manning, M. & M.
Mason-Neilan Reg.
Moeller Inst. Co.
N. Y. Laboratory Sup.
Palmer Co.
Palo-Myers
Parks-Cramer Co.
Phila. Therm. Co.
Powers Reg. Co.
Precision Scien. Co.
Precision T. & I.
Sargent & Co., E. H.
Scientific Glass App.
Scientific Inst. Co.
Tagliabue Mfg.
Taylor Inst. Cos.
Thomas Co., A. H.
Wheelco Inst. Co.
Will Corp.

HYDROGEN-ION
American Inst. Co.
Braun Corp.
Burrell Tech. Sup.
Cambridge Inst. Co.
Cargille, R. P.
Central Scientific Co.
Coleman Elec. Co.
Colloid Equip. Co.
Daigger & Co., A.
Eimer & Amend
Elgin Softener
Fisher Scientific Co.
Foxboro Co.
Gen. Elec. Co.
Greiner, Inc., Emil
Greiner & Co., Otto
Hellige, Inc.
Indust. Insts. Inc.
Klett Mfg. Co.
La Motte Chem.
La Pine & Co.
Leeds & Northrup
Leitz, E.
Nat'l. Tech. Labs.
N. Y. Laboratory Sup.
Palo-Myers
Sargent & Co., E. H.
Scientific Glass App.
Taylor & Co., W. A.
Thomas Co., A. H.
Thwing-Albert
Wilkens-Anderson
Will Corp.

HYDROMETERS
Braun Corp.
Burrell Tech. Sup.
Central Scientific Co.
Claflin Co.
Daigger & Co., A.
Eimer & Amend
Elgin Softener
Fisher Scientific Co.
Fleischhauer
Greiner, Inc., Emil
Greiner & Co., Otto
H-B Instrument Co.
La Pine & Co.
Moeller Inst. Co.
N. Y. Laboratory Sup.
Palo-Myers
Permutit Co.
Phila. Therm. Co.
Precision T. & I.
Ruehfel Co.
Sargent & Co., E. H.
Scientific Glass App.
Scientific Inst. Co.
Tagliabue Mfg.
Taylor Inst. Cos.
Thomas Co., A. H.
Uehling Inst. Co.
Will Corp.

HYGROMETERS, See Humidity

HYGROSTATS, See Humidity

HYGROTHERMOGRAPHS, See Humidity

I

IGNITION VELOCITY
American Inst. Co.
Hays Corp.

ILLUMINATION
Central Scien. Co.
G-M. Labs.
Gen. Elec. Co.
Intercontinental
Leeds & Northrup
Luxtrol, Inc.
Weston Elec. Inst.

IMPACT TESTING See Tensile Testing

INDUCTANCE, See Electrical Measuring

INSTRUMENTS, Custom Built
Ace Glass
American Inst. Co.
Braun Corp.
Burrell Tech. Sup.
Bushnell & Nevius
Central Scientific Co.
Daigger & Co., A.
Eimer & Amend
Fisher Scientific Co.
Greiner, Inc., Emil
Greiner & Co., Otto
L.A.B. Corp.
N. Y. Laboratory Sup.
Sargent & Co., E. H.
Scientific Glass App.
Thomas Co., A. H.
Will Corp.

INSULATION, Compactness
Central Scientific Co.

INSULATION TESTING, See Electrical Measuring

INTERFEROMETERS
Gaertner Scientific
Jarrell-Ash
Perkin, E. & M.
Zeiss, Inc., Carl

IRON CHILL TESTING
Dietert Co., H. W.

J

JELLY STRENGTH See Glue Testing

K

KYMOGRAPH
Gorrell & Gorrell

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For complete name and address of companies listed in this index consult page 21

Continued from Page 38

L

M

For complete name and address of companies listed in this index consult page 21

MICROSCOPES (and accessories)
B. & L. Optical
Braun Corp.
Buehler, A. I.
Burrell Tech. Sup.
Central Scientific Co.
Clay-Adams Co.
Daigger & Co., A.
Dietert Co., H. W.
Eimer & Amend
Fisher Scientific Co.
Gaertner Scientific
Greiner, Inc., Emil
Greiner & Co., Otto
Jarrell-Ash Co.
La Pine & Co.
Leitz, E.
Microchemical Service
N. Y. Laboratory Sup.
N. Y. Scientific Sup.
Pfaltz & Bauer
Palo-Myers
Sargent & Co., E. H.
Scientific Glass App.
Spencer Lens Co.
Thomas Co., A. H.
Will Corp.
Zeiss, Inc., Carl

MICRO-MANIPULATORS
Hoffman Co.
Industrial Insts.
Leitz, Inc., E.
Microchemical Service
Mico Instrument
Zeiss, Inc., Carl

MICROVOLTMETERS See Electrical Measuring

MILK TESTING SETS
Braun Corp.
Burrell Tech. Sup.
Central Scientific Co.
Daigger & Co., A.
Eimer & Amend
Fisher Scientific Co.
Gen. Elec. Co.
Greiner, Inc., Emil
Greiner & Co., Otto
La Pine & Co.
N. Y. Laboratory Sup.
Palo-Myers
Sargent & Co., E. H.
Scientific Glass App.
Thomas Co., A. H.
Will Corp.

MILLIAMMETERS See Electrical Measuring

MILLIOHMMETERS See Electrical Measuring

MILLIVOLTMETERS See Electrical Measuring

MOBILOMETER
Gardner Lab., H. A.

MOISTURE METERS AND TESTING
American Inst. Co.
Brabender Corp.
Braun Corp.
Burrell Tech. Sup.
Cambridge Inst. Co.
Central Scientific Co.
Colloid Equip. Co.
Corning Glass Wks.
Daigger & Co., A.
Dietert Co., H. W.
Eimer & Amend
Fisher Scientific Co.
Greiner, Inc., Emil
Greiner & Co., Otto
Industrial Inst., Inc.
La Pine & Co.
N. Y. Laboratory Sup.
Precision Scientific
Palo-Myers
Sargent & Co., E. H.
Scientific Glass App.
Scientific Inst. Co.
Tagliabue Mfg.
Thomas Co., A. H.
Will Corp.

MOLECULAR STILLS
Distillation Prod., Inc.

N

NEPHELOMETERS See Color Measuring

NIGROMETERS, See Color Measuring

NITROGEN DETERMINATION
Ace Glass
American Inst. Co.
Braun Corp.
Burrell Tech. Sup.
Central Scientific Co.
Daigger & Co., A.
Eck & Krebs
Eimer & Amend
Fisher Scientific Co.
Greiner, Inc., Emil
Greiner & Co., Otto
Laboratory Const.
La Pine & Co.
N. Y. Laboratory Sup.
Palo-Myers
Precision Scientific
Sargent & Co., E. H.
Scientific Glass App.
Scientific Inst.
Thomas Co., A. H.
Will Corp.

NOISE MEASURING See Sound

O

OHMMETERS, See Electrical Measuring

OIL TESTING
Ace Glass
American Inst. Co.
Braun Corp.
Burrell Tech. Sup.
Central Scientific Co.
Daigger & Co., A.
Eck & Krebs
Eimer & Amend
Fisher Scientific Co.
Greiner, Inc., Emil
Greiner & Co., Otto
Kimble Glass
La Pine & Co.
N. Y. Laboratory Sup.
Palo-Myers
Precision Scientific
Sargent & Co., E. H.
Scientific Glass App.
Scientific Inst. Co.
Tagliabue Mfg.
Thomas Co., A. H.
Will Corp.

OPACIMETERS, See Light Measuring

OPERATION RECORDING
Bailey Meter Co.
Bristol Co.
Brown Inst.
Esterline-Angus
Foxboro Co.
Mason-Neilan Reg.
Tagliabue Mfg.

OPTICAL FLATS
B & L Optical
Ferner Co.
Fish-Schurman
Gaertner Scientific
Perkin, E. & M.
Scherr Co., Inc.

ORSAT APPARATUS See Gas Analyzers; Combustion Sets

ORTHO-TOLIDIN TESTING SETS
Hellige, Inc.
LaMotte Chem. Prod.
Taylor & Co., W. A.

OXYGEN, See Gas Analyzers

P

PAINT HIDING POWER, See Paint Testing

PAINT TESTING
Atlas Elec. Dev.
Braun Corp.
Burrell Tech. Sup.
Cargille, R. P.
Central Scientific Co.
Daigger & Co., A.
Eimer & Amend
Fisher Scientific Co.
Gardner Lab., H. A.
Greiner, Inc., Emil
Greiner & Co., Otto
Hellige, Inc.
La Pine & Co.
N. Y. Laboratory Sup.
Palo-Myers
Sargent & Co., E. H.
Scientific Glass App.
Scientific Inst. Co.
Spencer Lens Co.
Thomas Co., A. H.
Will Corp.

PAPER TESTING
American Inst. Co.
Amthor Test. Inst.
Atlas Elec. Devices
Boulin Inst. Corp.
Braun Corp.
Burrell Tech. Sup.
Central Scientific Co.
Daigger & Co., A.
Eimer & Amend
Fisher Scientific Co.
Greiner, Inc., Emil
Greiner & Co., Otto
Gurley, W. & L. E.
La Pine & Co.
N. Y. Laboratory Sup.
Palo-Myers
Perkins & Son, B. F.
Precision T. & I.
Sargent & Co., E. H.
Saxl Inst. Co.
Scientific Glass App.
Scott, H. L.
Spencer Lens Co.
Taber Instrument Co.
Thomas Co., A. H.
Thwing-Albert Inst.
Will Corp.

PARAFFIN TESTING See Oil Testing

PARTICLE SIZE CLASSIFIERS, See also Sieves, Testing
American Inst. Co.
Colloid Equip. Co., Inc.
Palo-Myers

PENETROMETERS
American Inst. Co.
Braun Corp.
Burrell Tech. Sup.
Central Scientific Co.
Daigger & Co., A.
Eimer & Amend
Fisher Scientific Co.
Greiner, Inc., Emil
Greiner & Co., Otto
La Pine & Co.
N. Y. Laboratory Sup.
Palo-Myers
Precision Scien. Co.
Sargent & Co., E. H.
Scientific Glass App.
Thomas Co., A. H.
Will Corp.

PERMEAMETERS, See Electrical Measuring

PERMEAMETERS, Soil
American Inst.

PETROLEUM TESTING, See Oil Testing

pH METERS, Indicating & Recording, See Hydrogen-ion

PHOSPHATASE TEST See Milk Testing

PHOSPHATE TESTERS, See Water Analysis Sets

PHOTOELECTRIC COLOR ANALYZERS See Light Measuring

PHOTOMETERS, See Light Measuring

PIEZOMETERS
Brush Devel. Co.

PIPE AND TUBE TESTING, See Tensile Testing

PITOT TUBES, See Flowmeters

PLANIMETERS
Bristol Co.
Brown Inst.
Crosby Steam G. & V.
Foxboro Co.
Gaertner Scientific
Keuffel & Esser
Taylor Inst. Cos.
Trill Indicator Co.

PLASTOMETERS
American Inst. Co.
Brabender Corp.
Gardner Labs., H. A.

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POLARIMETERS (and accessories)
Akatos, Inc.
B. & L. Optical Co.
Braun Corp.
Burrell Tech. Sup.
Central Scientific Co.
Daigger & Co., A.
Eimer & Amend
Fisher Scientific Co.
Gaertner Scientific
Greiner, Inc., Emil
Greiner & Co., Otto
Jarrell-Ash Co.
Leitz, E.
N. Y. Laboratory Sup.
Sargent & Co., E. H.
Scientific Glass App.
Thomas Co., A. H.
Will Corp.
Zeiss, Inc., Carl

POLARISCOPES, See Polarimeters

POLAROGRAPHS, see Dropping Mercury Electrode

POROSITY
Gurley, W. & L. E.
Saxl Inst. Co.
Testing Machines

POTENTIOMETERS AND BRIDGES
Braun Corp.
Bristol Co.
Brown Inst.
Burrell Tech. Sup.
Cambridge Inst. Co.
Central Scientific Co.
Daigger & Co., A.
Eimer & Amend
Fisher Scientific Co.
Foxboro Co.
General Radio Co.
Gen. Elec. Co.
Greiner, Inc., Emil
Greiner & Co., Otto
Hellige, Inc.
Industrial Inst., Inc.
J. B. T. Instruments
La Pine & Co.
Leeds & Northrup
Lewis Eng. Co.
N. Y. Laboratory Sup.
Palo-Myers
Rubicon Co.
Sargent & Co., E. H.
Scientific Glass App.
Tagliabue Mfg.
Thomas Co., A. H.
Westinghouse E. & M.
Wheelco Inst. Co.
Weston Elec. Inst.
Will Corp.

POWER FACTOR, See Electrical Measuring

PRESSURE AND VACUUM
See also Barometers; Gages, McLeod, Mercury; Manometers; Vacuum Gage, Pirani Type
Ace Glass
American Inst. Co.
American Meter Co.
Ames Co.
Arca Reg., Inc.
Automatic Temp. Con.
Bailey Meter Co.
Braun Corp.
Bristol Co.
Brown Inst.
Burrell Tech. Sup.
Bushnell & Nevius
Cambridge Inst. Co.
Cash Co.
Central Scientific Co.
Clark Blast Meter
Cochrane Corp.
Continental Elec. Co.
Crosby Steam G. & V.
Daigger & Co., A.
Defender Auto. Reg.
Distillation Prod. Inc.
Dubrovin, John
Eclipse Fuel Eng.
Eimer & Amend
Fisher Scientific Co.
Foster Eng. Co.
Foxboro Co.
Fulton Sylphon
Gen. Elec. Co.
Gleason-Avery, Inc.
Greiner, Inc., Emil
Greiner & Co., Otto
Hagan Corp.
Hays Corp.
Hoke, Inc.
Kieley & Mueller
La Pine & Co.
Linde Air Prod.
Manning, M. & M.
Marsh Corp., J. P.
Mason Neilan Reg.
Mercon Reg. Co.
Meriam Co.
Natural Gas Equip.
New Jersey Meter
N. Y. Laboratory Sup.
Palo-Myers
Powers Reg. Co.
Precision Scientific
Precision T. & I.
RCA Mfg. Co.
Rep. Flow Meters
Sargent & Co., E. H.
Scientific Glass App.
Scientific Inst. Co.
Spence Eng. Co.
Tagliabue Mfg.
Taylor Inst. Cos.
Thomas Co., A. H.
Uehling Inst. Co.
Wheelco Inst. Co.
Will Corp.

PROTRACTORS, See Lineal Dimensions

PROVING RINGS
Baldwin-Southwark
Holz, H. A.
Morehouse, Mach.
Olsen Test. Mach.
Pgh. Inst. & Mach.

PSYCHROMETERS
See Humidity

PULP TESTING
Perkins & Sons
Testing Machines Inc.

PULVERIZED MATERIALS MEASURING
See Granular Material Meters; Particle Size Classifiers; Sieves, Testing

PYCNOMETERS
Ace Glass
American Inst. Co.
Braun Corp.
Central Scientific Co.
Daigger & Co., A.
Eimer & Amend
Fisher Scientific Co.
Greiner, Inc., Emil
Greiner & Co., Otto
Kimble Glass
La Pine & Co.
N. Y. Laboratory Sup.
Palo-Myers
Sargent & Co., E. H.
Scientific Glass App.
Thomas Co., A. H.
Will Corp.

PYROMETERS
Akatos, Inc.
Bacharach Ind. Inst.
Braun Corp.
Bristol Co.
Brown Inst.
Burrell Tech. Sup.
Cambridge Inst. Co.
Central Scientific Co.
Daigger & Co., A.
Defender Auto Reg.
Dietert Co., H. W.
Eck & Krebs
Eimer & Amend
Engelhard, Inc.
Fisher Scientific Co.
Foxboro Co.
Gordon Co., C. S.
Greiner, Inc., Emil
Greiner & Co., Otto
Hoskins Mfg. Co.
Illinois Test. Labs.
J. B. T. Instruments
La Pine & Co.
Leeds & Northrup
Lewis Eng. Co.
N. Y. Laboratory Sup.
Palo-Myers
Phila. Therm. Co.
Partlow Corp.
Pyrometer Inst. Co.
Rawson Elec. Inst.
Rubicon Co.
Sargent & Co., E. H.
Scientific Glass App.
Scientific Inst. Co.
Tagliabue Mfg.
Taylor Inst. Cos.
Thomas Co., A. H.
Thwing-Albert
Weston Elec. Inst.
Wheelco Inst. Co.
Will Corp.

PYROMETRIC CONES
Accurate Pyro. Cone
Orton Ceram. F'd'n

R

RADIOACTIVE
Geophysical Inst. Co.

REACTANCE, See Electrical Measuring

RECTIFIERS, See Electronic

REFLECTION METERS, See Light Measuring

REFLECTOMETERS
See Light Measuring

REFRACTOMETERS
B. & L. Optical Co.
Braun Corp.
Burrell Tech. Sup.
Cargille, R. P.
Central Scientific Co.
Daigger & Co., A.
Eimer & Amend
Fisher Scientific Co.
Greiner, Inc., Emil
Greiner & Co., Otto
Industro Scient.
Leitz, E.
N. Y. Laboratory Sup.
Pfaltz & Bauer
Sargent & Co., E. H.
Scientific Glass App.
Spencer Lens Co.
Thomas Co., A. H.
Will Corp.
Zeiss, Inc., Carl

RELAYS,
Allied Contaol
American Automatic
American Instrument
Bunnell and Co.
Clare & Co.
Dunn, Struthers
Eby, Inc.
Gen. Elec. Co.
G-M Labs.
Guardian Electric
Kurman Elec. Co.
Leach Relay Co.
Photoswitch, Inc.
Precision T. & I.
Sigma Insts., Inc.
Ward Leonard
Westinghouse E. & M.
Weston Elec. Inst.
Wheelco Inst. Co.

REMOTE METERING
See Telemetering

RHEOSTATS, See Electrical Measuring

RESISTANCE BOXES
See Electrical Measuring

ROAD MATERIAL TESTING, See also Specific Materials, Cement, etc.
American Inst. Co.

ROCKWELL HARDNESS, See Hardness Testing
Wilson Mech. Inst.

ROTAMETERS
Fischer & Porter
Schutte & Koerting

For complete name and address of companies listed in this index consult page 21

RUBBER TESTING
American Inst. Co.
Amthor Test. Inst.
Braun Corp.
Burrell Tech. Sup.
Central Scientific Co.
Daigger & Co., A.
Eimer & Amend
Fisher Scientific Co.
Greiner, Inc., Emil
Greiner & Co., Otto
La Pine & Co.
Morehouse Mach.
N. Y. Laboratory Sup.
Palo-Myers
Sargent & Co., E. H.
Scientific Glass App.
Scott, H. L.
Thomas Co., A. H.
Will Corp.

RULES, See Lineal Dimensions

S

SACCHARIMETERS
See Polarimeters

SACCHAROMETERS
See Hydrometers

SALINITY MEASURING
Braun Corp.
Burrell Tech. Sup.
Central Scientific Co.
Daigger & Co., A.
Eimer & Amend
Fisher Scientific Co.
Greiner, Inc., Emil
Greiner & Co., Otto
H-B Inst. Co.
Industrial Inst. Co.
La Pine & Co.
Leeds & Northrup
N. Y. Laboratory Sup.
Palo-Myers
Sargent & Co., E. H.
Scientific Glass App.
Tagliabue Mfg.
Taylor Inst. Cos.
Thomas Co., A. H.
Will Corp.

SALINOMETERS, See Hydrometers

SAND TESTING
Ace Glass
American Inst. Co.
Braun Corp.
Burrell Tech. Sup.
Central Scientific Co.
Daigger & Co., A.
Dietert Co., H. W.
Eimer & Amend
Fisher Scientific Co.
Greiner, Inc., Emil
Greiner & Co., Otto R.
La Pine & Co.
N. Y. Laboratory Sup.
Palo-Myers
Sargent & Co., E. H.
Scientific Glass App.
Thomas Co., A. H.
Will Corp.

SCALES, Gravimetric
Atlas Car & Mfg.
Becker, Christian
Braun Corp.
Burrell Tech. Sup.
Central Scientific Co.
Daigger & Co., A.
Eimer & Amend
Exact Weight Scale
Fairbanks Morse
Fisher Scientific Co.
Greiner, Inc., Emil
Greiner & Co., Otto
Gump Co.
Howe Scale Co.
Kron Co.
La Pine & Co.
Merrick Scale
N. Y. Laboratory Sup.
Palo-Myers
Precision Scientific
Sargent & Co., E. H.
Scientific Glass App.
Thomas Co., A. H.
Torsion Balance
Toledo Scale
Troemner, Henry

SCRATCH HARDNESS
Dietert Co., H.
Holz, H. A.
Spencer Lens
Taber Inst. Co.
Testing Mach. Inc.

SCREENS, Testing, See Sieves, Testing

SEGER CONES, See Cones, Pyrometric

SHEARING TESTING
See Tensile Testing

SHEET METAL TESTING, See Tensile Testing

SIEVES, Testing
American Inst. Co.
Braun Corp.
Central Scientific Co.
Daigger & Co., A.
Eimer & Amend
Fisher Scientific Co.
Greiner, Inc., Emil
Greiner & Co., Otto
La Pine & Co.
Newark Wire
N. Y. Laboratory Sup.
Palo-Myers
Precision Scientific
Sargent & Co., E. H.
Scientific Glass App.
Thomas Co., A. H.
Tyler Co., W. S.
Will Corp.

SIGHT METERS, See Illumination

SLOWNESS TESTERS
Saxl Inst. Co.
Testing Mach. Inc.

SMOKE DENSITY
Bailey Meter
Boiler Room Equip.
Bristol Co.
Ess Inst. Co.
Genl. Elec. Co.
Leeds & Northrup
Luxtrol Co.
Photoswitch Inc.
Weston Elect. Inst.

SOFTNESS TESTERS
Ferner Co.
Gurley, W. & L. E.
Saxl Inst. Co.
Taber Inst. Co.
Thwing-Albert

SOIL TESTING
American Inst. Co.
LaMotte Chem. Prod.

SOUND MEASURING
Elec. Res. Prod.
Genl. Elect. Co.
General Radio Co.
Televiso Prod.
Triplett Elec.
Westinghouse E. & M.
Weston Elect. Inst.

SPECIAL INSTRUMENTS
Ace Glass, Inc.
American Inst. Co.
Braun Corp.
Bushnell & Nevius
Central Scientific Co.
Daigger & Co., A.
Eimer & Amend
Fisher Scientific Co.
Greiner, Inc., Emil
Greiner & Co., Otto
Hellige, Inc.
Hopf Glass App. Co.
L.A.B. Corp.
La Pine & Co.
Machlett & Son
N. Y. Laboratory Sup.
Palo-Myers
Precision Scien. Co.
Sargent & Co., E. H.
Scientific Glass App.
Scott, H. L.
Thomas Co., A. H.
Will Corp.

SPECIFIC GRAVITY MEASURING
Ace Glass
American Meter Co.
Bailey Meter Co.
Braun Corp.
Burrell Tech. Sup.
Central Scientific Co.
Daigger & Co., A.
Eimer & Amend
Fisher Scientific Co.
Foxboro Co.
Greiner, Inc., Emil
Greiner & Co., Otto
Kimble Glass
La Pine & Co.
N. Y. Laboratory Sup.
Palo-Myers
Sargent & Co., E. H.
Scientific Glass App.
Tagliabue Mfg.
Taylor Inst. Cos.
Thomas Co., A. H.
Will Corp.

SPECTROGRAPHS
See Spectrometers

SPECTROMETERS
(and accessories)
Akatos, Inc.
American Inst. Co.
Applied Res. Labs.
B. & L. Optical Co.
Braun Corp.
Buehler, A. I.
Burrell Tech. Sup.
Central Scientific Co.
Daigger & Co., A.
Dietert Co., H. W.
Eimer & Amend
Fish-Schurman
Fisher Scientific Co.
Gaertner Scientific
Greiner, Inc., Emil
Greiner & Co., Otto
Jarrell-Ash Co.
La Pine & Co.
Leitz, Inc., E.
N. Y. Laboratory Sup.
Palo-Myers
Pfaltz & Bauer
Sargent & Co., E. H.
Scientific Glass App.
Spencer Lens Co.
Thomas Co., A. H.
Will Corp.
Zeiss, Inc., Carl

SPECTROPHOTOMETERS (and accessories)
Akatos, Inc.
B. & L. Optical Co.
Central Scientific
Coleman Electric Co.
Dietert Co., H. W.
Frober-Faybor
Gaertner Scientific
Gen. Elec. Co.
Jarrell-Ash Co.
Spencer Lens Co.

SPECTROSCOPES
See Spectrometers

SPEED INDICATORS
See also Tachometers
Arca Regulators
Boulin Inst. Corp.
Braun Corp.
Central Scientific Co.
Daigger & Co., A.
Eimer & Amend
Elec. Speed Ind. Co.
Electric Tach.
Fischer Scientific Co.
Greiner, Inc., Emil
Greiner & Co., Otto
N. Y. Laboratory Sup.
Republic Flow
Sargent & Co., E. H.
Scientific Glass App.
Thomas Co., A. H.
Veeder-Root
Weston Elect. Inst.
Will Corp.

SPHEROMETERS
Central Scient. Co.
Fish-Schurman
Gaertner Scientific

SPHYGMOMANOMETERS
Braun Corp.
Burrell Tech. Sup.
Central Scientific Co.
Daigger & Co., A.
Eimer & Amend
Fisher Scientific Co.
Greiner, Inc., Emil
Greiner & Co., Otto
La Pine & Co.
N. Y. Laboratory Sup.
Palo-Myers
Precision T. & I.
Sargent & Co., E. H.
Scientific Glass App..
Scientific Inst. Co.
Taylor Inst. Cos.
Thomas Co., A. H.
Will Corp.

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For complete name and address of companies listed in this index consult page 21

Pyrometer Inst. Co.
Republic Flow
Sarco Co.
Spence Eng. Co.
Sterling Eng. Co.
Sup. Elec. Prod.
Tagliabue Mfg.
Taylor Inst. Cos.
Thwing-Albert
Uehling Inst. Co.
Weston Elec. Inst.
Wheelco Inst. Co.

TENDERNESS
American Inst. Co.
Braun Corp.
Central Scientific Co.
Daigger & Co., A.
Eimer & Amend
Fisher Scientific Co.
Greiner, Inc., Emil
Greiner & Co., Otto
La Pine & Co.
N. Y. Laboratory Sup.
Palo-Myers
Precision Scientific
Sargent & Co., E. H.
Saxl Inst. Co.
Scientific Glass App.
Thomas Co., A. H.
Will Corp.

TENSILE TESTING
American Inst. Co.
Amthor Test. Inst.
Baldwin-Southwark
Braun Corp.
Burrell Tech. Sup.
Central Scientific Co.
Daigger & Co., A.
Eimer & Amend
Ferner Co.
Fisher Scientific Co.
Gen. Elec. Co.
Greiner, Inc., Emil
Greiner & Co., Otto
Holz, H. A.
La Pine & Co.
Linde Air Prod.
N. Y. Laboratory Sup.
Olsen Test. Mach.
Palo-Myers
Perkins & Son
Riehle Test Div.
Sargent & Co., E. H.
Saxl Inst. Co.
Scientific Glass App.
Scott, H. L.
Suter, A.
Test. Mach. Inc.
Thomas Co., A. H.
Thwing-Albert
Sargent & Co., E. H.
Will Corp.

TENSIOMETERS, Surface Tension
Braun Corp.
Central Scientific Co.
Daigger & Co., A.
Eimer & Amend
Fisher Scientific Co.
Greiner, Inc., Emil
Greiner & Co., Otto
La Pine & Co.
N. Y. Laboratory Sup.
Palo-Myers
Sargent & Co., E. H.
Scientific Glass App.
Thomas Co., A. H.
Will Corp.

TEST WEIGHTS, See Weights

TESTERS AND TESTING MACHINES, See subject of measurement

TEXTILE TESTING
American Inst. Co.
Atlas Elec. Devices
Boulin Inst. Corp.
Braun Corp.
Burrell Tech. Sup.
Cambridge Inst. Co.
Central Scientific Co.
Daigger & Co., A.
Eimer & Amend
Fisher Scientific Co.
Greiner, Inc., Emil
Greiner & Co., Otto
Gurley, W. & L. E.
La Pine & Co.
N. Y. Laboratory Sup.
Palo-Myers
Perkins & Son
Sargent & Co., E. H.
Saxl Inst. Co.
Scientific Glass App.
Scott, H. L.
Sheffield Gage
Spencer Lens Co.
Suter, A.
Taber Inst. Co.
Thomas Co., A. H.
Thwing-Albert Inst.
Will Corp.

THERMO-AMMETERS See Electrical Measuring

THERMO-ANEMOMETER
Willson Products, Inc.

THERMOCOUPLES See Pyrometers

THERMO-HYDROMETERS, See Hydrometers

THERMOMETERS
American Inst. Co.
Bailey Meter Co.
Braun Corp.
Bristol Co.
Brown Inst.
Burrell Tech. Sup.
Cambridge Inst. Co.
Central Scientific Co.
Claflin Co.
Daigger & Co., A.
Defender Auto. Reg.
Eck & Krebs
Eimer & Amend
Engelhard, Inc.
Faichney Inst. Corp.
Fisher Scientific Co.
Fleischhauer & Son
Foxboro Co.
Gaertner Scientific
Gotham Inst. Co.
Green, H. J.
Greiner, Inc., Emil
Greiner & Co., Otto
H-B Inst. Co.
Illinois Test. Labs.
Industrial Inst. Co.
Kessling Therm. Co.
La Pine & Co.
Liquidometer Corp.
Manning, M. & M.
Marsh Corp., J. P.
Mason Neilan Reg.
Moeller Inst. Co.
N. Y. Laboratory Sup.
Palmer Co.
Palo-Myers
Partlow Corp.
Pecorella Mfg. Co.
Permutit Co.
Phila. Therm. Co.
Powers Reg. Co.
Precision T. & I.
Rep. Flow Meters
Ruehfel, Geo.
Sarco Co., Inc.
Sargent & Co., E. H.
Scientific Glass App.
Scientific Inst. Co.
Tagliabue Mfg.
Taylor Inst. Co.
Thomas Co., A. H.
Thwing-Albert Inst.
Weston Elec. Inst.
Will Corp.

THERMOPILES
Cambridge Inst. Co.
Eppley Lab., Inc.

THERMOSTATS
American Inst. Co.
Braun Corp.
Brown Inst. Co.
Burling Inst. Co.
Burrell Tech. Sup.
Bushnell-Nevius
Central Scientific Co.
Daigger & Co., A.
Eimer & Amend
Fenwal Inc.
Fish-Schurman
Fisher Scientific Co.
Foxboro Co.
Friez & Sons
Fulton Sylphon
General Elec.
Greiner, Inc., Emil
Greiner & Co., Otto
H-B Inst. Co.
La Pine & Co.
Mercoid Corp.
Micro Switch Corp.
N. Y. Laboratory Sup.
Palo-Myers
Partlow Corp.
Phila. Therm. Co.
Powers Reg. Co.
Precision Scientific
Precision T. & I.
Robertshaw Therm.
Sargent & Co., E. H.
Scientific Glass App.
Supreme Elec. Prod.
Tagliabue Mfg.
Thomas Co., A. H.
Thrush & Co.
Will Corp.

THREAD TESTING See Textile Testing

TIME MEASURING, Cycle and Interval, See also Stop Watches
American Inst. Co.
Auto. Elec. Mfg.
Auto. Temp. Con.
Barber-Coleman
Betts & Betts
Braun Corp.
Bristol Co.
Brown Inst.
Burrell Tech. Sup.
Calculagraph Co.
Cambridge Inst. Co.
Central Scientific Co.
Clebar Watch Co.
Coleman Elec. Co.
Cramer Co., Inc.
Daigger & Co., A.
Dunn, Struthers
Eagle Signal Corp.
Eimer & Amend
Esterline-Angus
Fisher Scientific Co.
Foxboro Co.
Frober-Faybor
Gaertner Scientific
General Radio
Gordon Co.
Greiner, Inc., Emil
Greiner & Co., Otto
Inter. Filter Co.
Inter. Mktng. Corp.
La Pine & Co.
Luxtrol Co.
Mason-Neilan Reg.
Manning M. & M.
N. Y. Laboratory Sup
Palo-Myers
Permutit Co.
Photoswitch
Precision Scientific
Republic Flow Meters
Sargent & Co., E. H.
Scientific Glass App.
Service Recorder Co.
Standard Elec. Time
Tagliabue Mfg.
Taylor Inst. Cos.
Thomas Co., A. H.
Thompson Clock Co.
Walser Auto. Timer
Weston Elec. Inst.
Wheelco Inst. Co.
Will Corp.

TITRATION APPARATUS, Electrometric
Cambridge Inst. Co.
Central Scientific Co.
Coleman Electric Co.
Fisher Scientific
Leeds and Northrup
Leitz, Inc., E.
National Tech. Labs.
Rubicon Co.
Sargent & Co., E. H.
Thomas Co., A. H.
Welch Scientific

TORSION, See Tensile Testing

TOTALIZERS, Fluid Flow, See Flowmeters

TURBIDIMETERS, See Color Measuring

TWIST COUNTERS See Textile Testing

U

ULTRA-VIOLET
Hanovia Chem.
Westinghouse E. & M.

U-TUBE MANOMETERS, See Manometers

V

VACUUM GAGE, McLeod type, See McLeod

VACUUM GAGE, Pirani Type; See also Pressure and Vacuum
Continental Electric
Distillation Prod. Inc.

VACUUM MEASURING See Pressure and Vacuum; Barometers; Gages Mercury and McLeod; Manometers

VALVE POSITION INDICATORS
Auto. Temp. Con.
Bailey Meter
Builders Iron
Foxboro Co.
Manning, M. & M.
Taylor Inst. Cos.
Tefft-Jackson

VAPOR DENSITY See Gas Analyzers

VAPOR TRANSMISSION
Cargille, R. P.
Thwing-Albert Inst.

VARNISH TESTING See Paint Testing

VENTURI METERS See Flowmeters

VIBRATION
American Inst. Co.
Brush Devel. Co.
Cambridge Inst. Co.
Electrical Res. Prod.
Gen. Elec. Co.
RCA Mfg. Co.
Sheffield Gage
Televiso Prod.

VISCOSIMETERS
Ace Glass
American Inst. Co.
Braun Corp.
Brookfield Eng. Lab.
Burrell Tech. Sup.
Cargille, R. P.
Central Scientific Co.
Colloid Equip. Co.
Daigger & Co., A.
Eimer & Amend
Fisher Scientific Co.
Fish-Schurman
Gardner Lab., H. A.
Gen. Elec. Co.
Greiner, Inc., Emil
Greiner & Co., Otto
Kimble Glass
La Pine & Co.
N. Y. Laboratory Sup.
Precision Scientific
Palo-Myers
Sargent & Co., E. H.
Scientific Glass App.
Scientific Inst. Co.
Tagliabue Mfg.
Thomas Co., A. H.
Will Corp.

VOLT-AMMETERS See Electrical Measuring

VOLTMETERS, See Electrical Measuring

VOLUMETER
Gardner Lab., H. A.

W

WATER ANALYSIS SETS
Ace Glass
Braun Corp.
Burrell Tech. Sup.
Central Scientific Co.
Chemlab Specialties
Cochrane Corp.
Daigger & Co., A.
Eimer & Amend
Elgin Softener
Fisher Scientific Co.
Greiner, Inc., Emil
Greiner & Co., Otto
Hellige, Inc.
Industrial Inst., Inc.
LaMotte Chem. Prod.
La Pine & Co.
N. Y. Laboratory Sup.
Palo-Myers
Precision Scient. Co.
Sargent & Co., E. H.
Scientific Glass App.
Tagliabue Mfg.
Taylor & Co., W. A.
Thomas Co., A. H.
Will Corp.

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