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TRANSPOSITIONS
A. G. CHAPMAN

**ACOUSTIC LEVEL
RECORDER**
E. H. BEDELL

MICROANALYSIS
H. W. HERMANCE

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In this Issue

BELL LABORATORIES
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Crystals of cadmium oxalate, photographed under angular transmitted illumination through a microscope

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Point Transposition

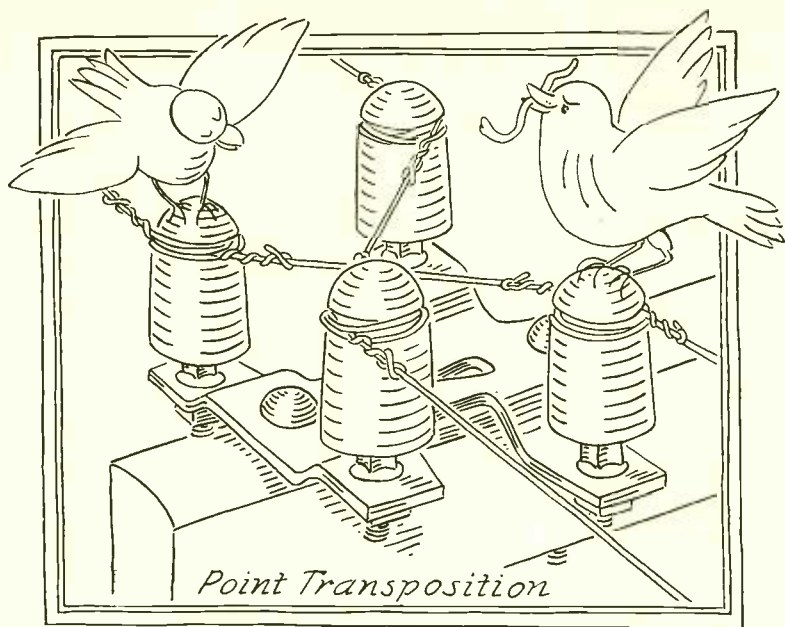# Some Principles of Transposing Open-Wire Lines

By A. G. CHAPMAN
Toll Transmission Development

CROSS *talk* over a telephone circuit is a matter dependent on the emotions and manners of the speakers. *Crosstalk* from one telephone circuit to an adjacent one is an action for the telephone engineer to prevent, and he takes particular pains that it shall not interfere with good telephone service.

Crosstalk* between open-wire circuits arises because of the electric and magnetic fields surrounding a pair of wires carrying a current. If the wires 1-2 of a telephone line, shown end-on in Figure 1, are carrying a current, the *magnetic field* produced by that current will be as indicated in the figure. As the current varies in

strength and direction from instant to instant, the magnetic lines expand or contract, cutting through the wires 3-4 of the adjacent pair and inducing voltages in them.

The *electric field*, surrounding the wires 1-2, has a similar diagram and a similar effect. It produces potentials at the surfaces of wires 3-4. Crosstalk currents flow in the wires 3-4 as a result of the potentials from both the electric and the magnetic fields.

The strengths of these currents depend on the strengths of the fields and the rapidity with which they change. Any increase of either the amplitude of the alternating current in a circuit, or the rapidity with which it alternates, tends at the same time to increase the crosstalk which that cur-

*A more complete discussion is given in the *Bell System Technical Journal* for *January*, 1934.

rent produces in neighboring circuits. It is for this reason that the tendency for crosstalk to take place between open-wire circuits was greatly increased by the advent of repeaters and of carrier-current methods for transmission. By increasing the power in telephone lines, repeaters increase the strengths in the surrounding fields, both electric and magnetic. The increased power makes possible long-distan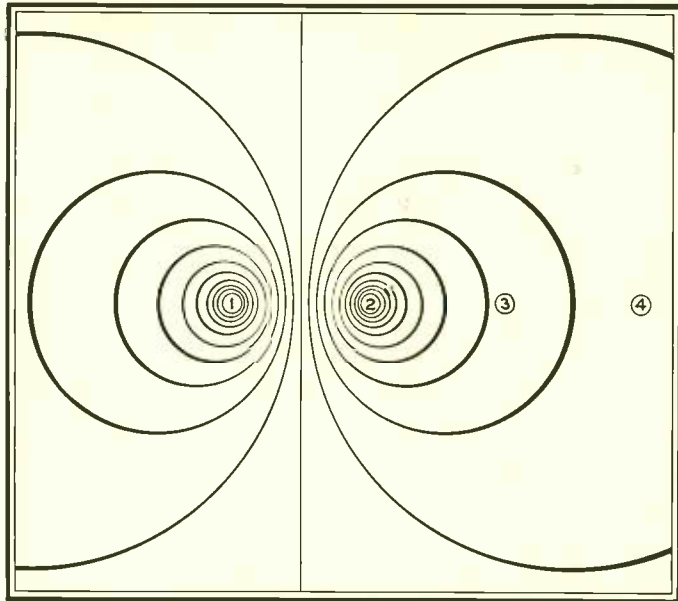ce transmission, but that involves greater lengths of lines in which crosstalk from one to another may occur. Carrier current transmission employs currents of higher frequency, and the more rapidly alternating fields along the lines result again in larger crosstalk currents. The problem of minimizing crosstalk has consequently become of increasing importance in recent years.

The voltage induced in any wire is due to the difference at the location of that wire between the two separate fields produced by the two wires of the disturbing circuit. Crosstalk can be reduced, therefore, by placing the wires of that circuit close

Fig. 1—Lines of force of the magnetic field, and equipotential lines of the electric field, with equal and opposite currents in wires 1 and 2

together. Similarly if the wires of the disturbed pair are also placed close together, the difference between the potentials at their locations, produced by the electric field, and the difference in the number of lines of magnetic force cut by the two, will be minimized. The wires of a pair, however, must be kept separated sufficiently to avoid contacts between them.

Crosstalk can be reduced also by arranging the wires in space so that each pair is "non-inductive" with respect to neighboring pairs. In the arrangement of two pairs shown in Figure 2, no lines of force from either pair cut through the other; and both wires of either pair are at the same potential in the electric field of the other pair. Unfortunately, it is difficult to place more than a very few circuits in such non-inductive configurations.

There is an even more important limitation to this method: crosstalk

Fig. 2—Between two circuits whose wires are arranged in this configuration no direct crosstalk will take place

takes place not only directly, from disturbing to disturbed circuits, but indirectly with the help of other circuits. This is because a circuit may induce crosstalk in some other circuit, which may then in turn induce into still another circuit. Even when, as in Figure 2, there are apparently only two circuits, at least two others exist which may furnish means for indirect crosstalk. These other circuits are shown in Figures 3A and 3B. One (3A) is a phantom circuit, in which the outgoing and returning paths are formed by the two pairs, respectively. The other (3B) is a circuit of which one side is formed by all four wires, and the return side is provided by the earth. Because of the existence of these other current paths,
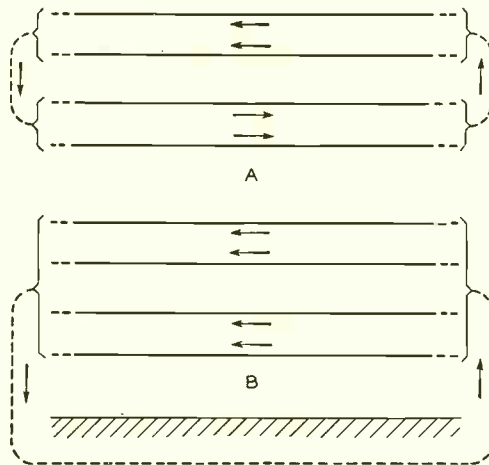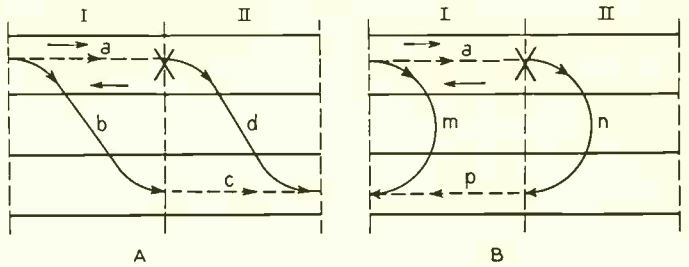

Fig. 4—Crosstalk between parallel circuits is conveniently visualized as taking place through couplings between segments of the circuits. A transposition in one circuit will balance one section against the following section for crosstalk of the far-end type (A), and will greatly reduce near-end crosstalk (B)

Fig. 3—Even when there are apparently only two circuits, there are really two more, with the aid of which "indirect" crosstalk may take place: a phantom circuit (A), and a circuit formed by all four wires and the ground (B)

there would be crosstalk between the two pairs.

The procedure actually used for reducing crosstalk is applicable to both the direct and the indirect types. The positions of the wires of a circuit are interchanged, or "transposed," at intervals along the line. If equal and opposite currents are flowing in the two wires of a circuit, a transposition reverses the phase of the fields produced by that circuit. The crosstalk current induced in an adjacent circuit by the segment of line preceding the transposition is then in phase opposition to that induced by the following segment, and the two currents tend to cancel.

If the strength and phase of the current in a line were the same at all points along it, the crosstalk induced by one segment could be completely balanced against that in the following segment by a single transposition. But currents are attenuated as they travel along a line, and the phase of the current at any instant is not the same at all points. By dividing the line into sufficiently small segments, the currents in adjacent segments will have approximately the same strength and phase. A transposition between two successive segments will then
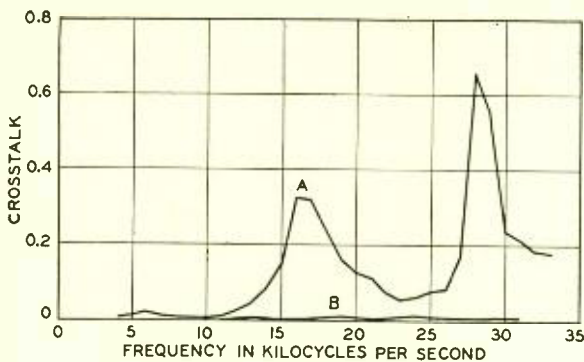
Fig. 5—*The crosstalk (Curve A) taking place when two circuits were transposed only for voice frequencies at the points T, shown in Figure 6, was greatly reduced (Curve B) by placing transpositions in both circuits at the points X. Crosstalk is shown as the ratio of currents received at the far ends of the disturbed and disturbing circuits, respectively*

crosstalk. A transposition is placed between the segments in the upper (disturbing) circuit.

In Figure 4A, a portion of the signal is shown traversing segment I of the upper circuit by the path *a*, and another portion passing into the parallel segment of the lower circuit through the far-end crosstalk coupling *b*. A portion of the signal which reaches segment II of the upper circuit passes into the corresponding segment of the lower circuit through the crosstalk coupling *d*. When a transposition is placed in the upper circuit, the phase of this current will be reversed and will tend to cancel the current which was produced in the lower circuit by the coupling *b* and proceeded through section II of the lower circuit by the path *c*. If the two circuits have identical properties, the two crosstalk paths *ad* and *bc* are identical. The far-end crosstalk components passing over these paths consequently suffer identical attenuations, and identical phase shifts except for the shift introduced by the transposition, and the transposition will practically

cause the crosstalk currents due to those segments to cancel almost completely.

Unlike the signal in the disturbing circuit, the crosstalk is propagated in both directions in the disturbed circuit: one portion in the same direction as the signal, called *far-end crosstalk*, and the other back toward the speaker, called *near-end crosstalk*. The effects of attenuation and phase change from section to section of the line are quite different for crosstalk propagated in the two directions. It is convenient to analyze these differences with the aid of simplified diagrams such as those in Figures 4A and 4B. There crosstalk between parallel circuits is visualized as taking place through couplings between segments of the circuits. Two segments, I and II, of a parallel between two circuits are shown in Figure 4A, for analysis of the far-end crosstalk, and the same two segments are shown again in Figure 4B, for the near-end
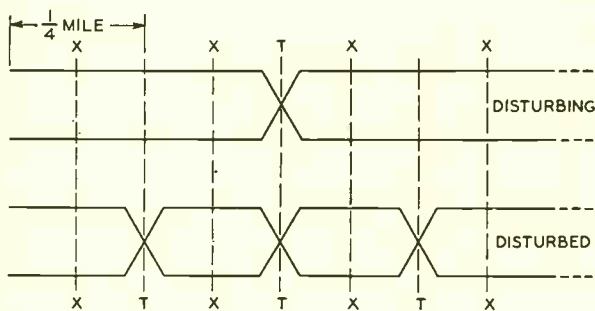

Fig. 6—*The crosstalk taking place between two circuits transposed as shown at the points T can be greatly reduced (Figure 5) by additional transpositions at the points X*

reduce the two components to zero.

Another portion of the signal in segment I of the upper circuit passes into the lower circuit through the near-end crosstalk coupling m, shown
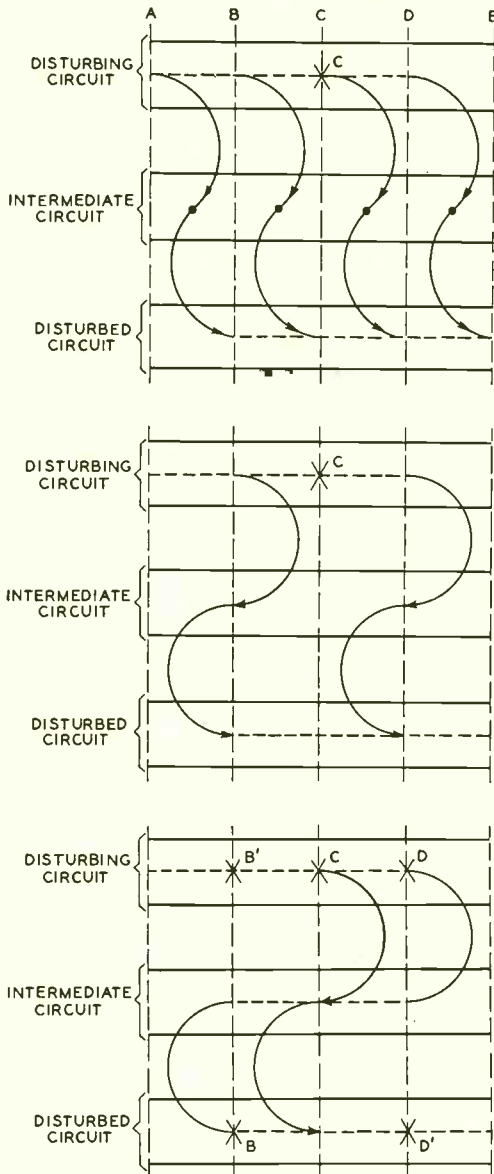

Fig. 7—*A transposition in one circuit will eliminate part of the far-end crosstalk taking place through intermediate circuits (above and center), and other transpositions will greatly reduce the remainder (below)*

in Figure 4B. A similar portion of the signal in segment II, which has arrived via the path a, and would be reversed in phase by a transposition, traverses the coupling n and proceeds over the lower circuit by the path p. Since the path anp is longer than the path m, the two near-end crosstalk components suffer different phase shifts and attenuations, aside from the shift caused by the transposition, and it is impossible to transpose so that they will cancel completely. The net crosstalk would be particularly serious at carrier frequencies. For this reason, the repeaters used in open-wire systems operating at carrier frequencies are one-way devices, and stop the near-end crosstalk before it can reach the terminals of the line.

They do not, however, stop the tendency of near-end crosstalk to produce far-end crosstalk. Near-end crosstalk will be reflected* toward the far-end at points of discontinuity either in the disturbed or disturbing circuit. Such "reflected near-end crosstalk" can be reduced by minimizing electrical discontinuities at points where it is necessary to change from one form of line construction to another, and at terminals where the lines are joined to apparatus.

Near-end crosstalk may also produce, indirectly through intermediate circuits, far-end crosstalk in another circuit. Much as two negatives make a positive, near-end crosstalk from one circuit to another, followed by near-end crosstalk from the latter circuit to a third, produces far-end crosstalk in that third circuit.

Here again transpositions can be put to use. Four short segments of a parallel between three circuits are shown three times over in Figure 7. These sketches indicate all the im-

*Record, *July* 1932, p. 374.

portant coupling paths which will produce far-end crosstalk indirectly in the disturbed circuit. The paths, each of which involves only one segment, are indicated in the uppermost diagram, and the paths involving two different segments are shown in the two lower diagrams.

The four couplings within the segments are similar to those shown at the left of Figure 4, in that the crosstalk from the two right-hand sections can be balanced against that from the left-hand sections if a single transposition is introduced at C. Similarly this transposition will cause cancellation of the crosstalk currents from the two paths in the center diagram.

The paths shown at the bottom of Figure 7 can be analyzed into two near-end crosstalk paths from the disturbing to the intermediate circuit, and two from the intermediate to the disturbed. As was shown at the right of Figure 4, crosstalk through the first pair of paths can be reduced, though not quite cancelled, by a transposition at D in the disturbing circuit; and that through the second pair can be reduced by a transposition at B in the disturbed circuit. To minimize crosstalk when the rôles of the disturbing and disturbed circuits are interchanged, two more transpositions are necessary (at B' in the upper circuit and at D' in the lower) but these do not affect the value of the transpositions already discussed.

It is interesting to notice from this analysis that transpositions placed at the same points in both disturbing and disturbed circuits, while of no value in reducing far-end crosstalk which takes place directly between two circuits, will greatly reduce far-end crosstalk which proceeds indirectly, through intermediate circuits. Often overlooked, the importance of the latter type of crosstalk, and the extent to which transpositions can reduce it, are shown by the measurements between horizontally adjacent pairs on a 140-mile line plotted in Figure 5. The scheme of transpositions for this line is shown in Figure 6.

The refinement of such principles as those discussed cannot completely eliminate crosstalk. A point is reached where unavoidable irregularities in the spacing of wires and poles make more difference in the crosstalk than a change in the transposition scheme. With the aid of these principles, however, transpositions have greatly reduced crosstalk in the long open-wire lines of the Bell System, and are essential to their operation.
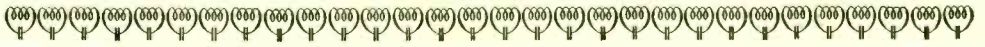
The Nature of Water Adsorbed On Cellulose

By G. T. KOHMAN

Chemical Laboratories

FOR most persons, water is a compound whose chemical composition is completely expressed by the formula H_2O, freezing to ice at 0° Centigrade, boiling to steam at 100°, and remaining liquid at intermediate temperatures. It has been inferred, however, by comparison with compounds of similar structure that if water were simply H_2O, it would boil at about minus 100° C.; and the human race and its dielectric problems would evaporate together. The properties of ordinary water suggest that it is a mixture of three "polymers," mono-, di-, and tri-hydrol (H_2O, H_4O_2, and H_6O_3), the relative proportions of which depend on the temperature and pressure.

The friendly behavior of water towards plants and animals is in sharp contrast to its rôle in certain parts of telephone equipment. There its presence in dielectrics is one of the commonest causes of electrical failure. The nature of water contained in dielectrics is probably even less understood than the nature of liquid water, and considerable study has therefore been given to it in these Laboratories.

All of the water adsorbed by fibrous materials such as cotton or paper does not possess the same characteristics. In a very wet sheet of paper, most of the water is held in large pores, much as in a sponge, and behaves quite like ordinary water. The water in most intimate contact with the surfaces of the fibers, however, seems to behave very differently. This becomes evident when the water is adsorbed at low humidities and when most of it is consequently in that intimate contact.

When water is adsorbed by a fibrous material at humidities below 50%, large quantities of heat are liberated. Indeed, carefully dried cotton or paper becomes noticeably warmer when suddenly exposed to a high humidity. By the use of a special technique it has been possible to measure the quantity of heat evolved when the first molecules are adsorbed. Thus it has been found that, at very low humidities, the heat evolved may exceed 250 calories per gram, or two and a half times the quantity of heat required to raise the temperature of the water from freezing to boiling.
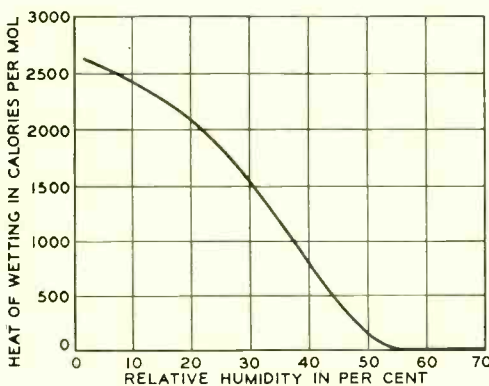

Fig. 1—The heat evolved during the adsorption by cellulose of water vapor from the air becomes rapidly less as the relative humidity increases

The evolution of so much heat is evidence of strong attractive forces acting between the water and the cellulose molecules. It can be seen in Figure 1 that the heat evolved per mole increases greatly as the humidity at which the water is adsorbed is reduced below 50%. Although the density of the adsorbed water cannot be measured directly, indirect measurements indicate that this property also varies in much the same manner with the humidity at which the water is adsorbed.

Fig. 2—The change in the current-voltage relationship in cellulose as it is dried is shown by the progressively lower curves

From these heat effects, the compressive forces which act upon the adsorbed water have been calculated to be of the order of 10,000 to 100,000 atmospheres. Such pressures are greater than those produced by the most powerful explosives, and hence it is extremely difficult, if not impossible, to remove water completely from cellulose.

If a relatively low pressure is applied to ordinary ice, the ice will melt because its volume is greater than that of the liquid formed upon melting. Professor P. W. Bridgman has shown that if the pressure is considerably increased the water will again freeze, but the ice formed is of a different sort, occupying a smaller volume than the liquid water. He has demonstrated that at least five varieties of ice can exist under different conditions. From his data it appears that, under pressures such as those estimated as obtaining in the water adsorbed on cellulose, ice will b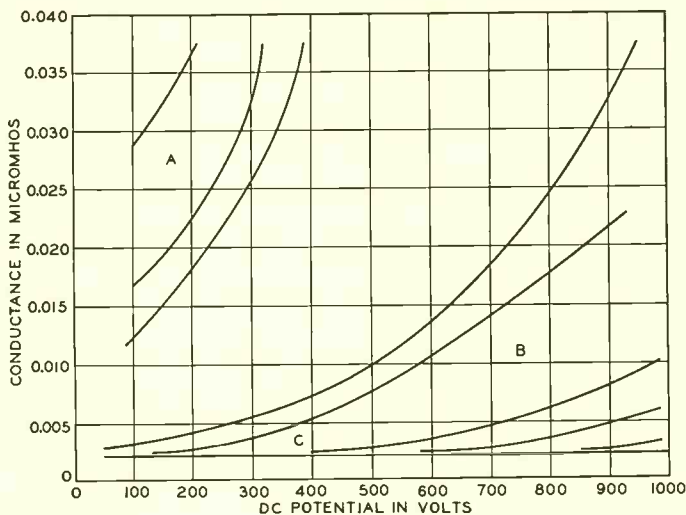e formed at temperatures as high as the boiling point of ordinary water. These considerations, together with other kinds of experimental evidence, strongly indicate that the water in relatively dry cellulose is present in some molecularly ordered form, such as in ice or in a salt hydrate.

When the cellulose is in equilibrium with higher humidities, there is probably a layer of highly compressed liquid water adsorbed on the still more highly compressed layer of ordered water, and there is evidence to indicate that the liquid water may be considerably dissociated. When water dissociates into its ions there is a decrease in volume, probably as a result of a closer packing of the ions and remaining molecules. From this volume change it follows that if pressure is applied to water the degree of dissociation must increase. It has been calculated that a pressure of 10,000 atmospheres is sufficient to increase the concentration of ions approximately ten fold. Effects of this kind may account in part for the high surface conductivity observed under certain conditions on fibrous materials.
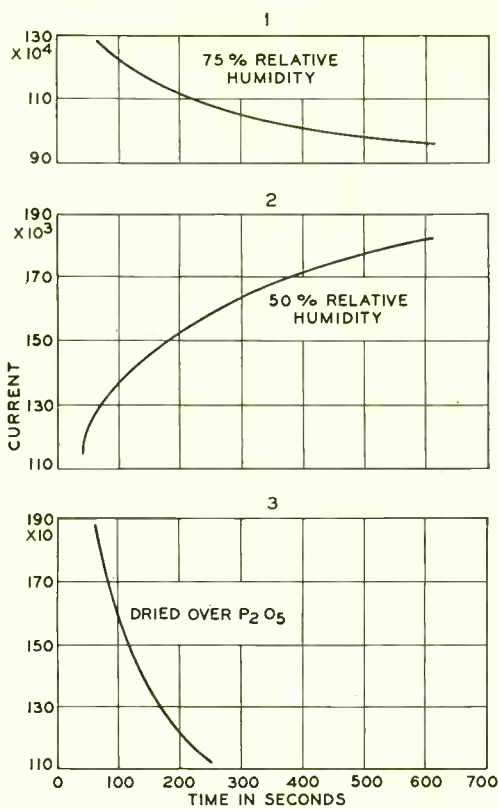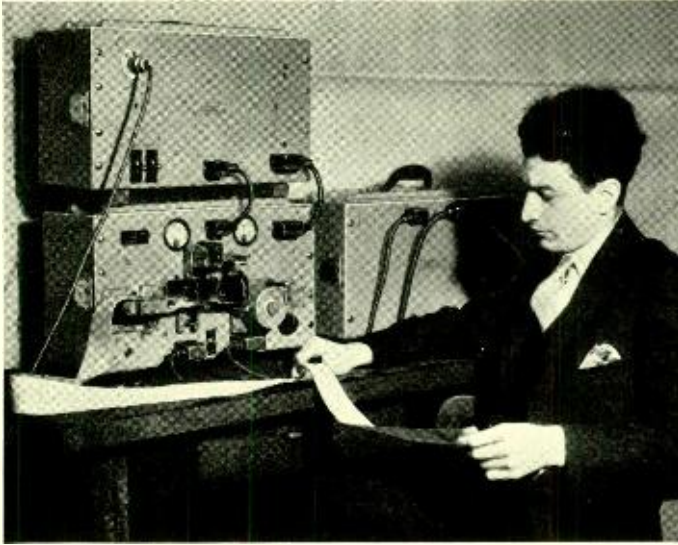
.Fig. 3—*The variation of the current in cellulose with time differs greatly at different relative humidities. Curve 1 corresponds to region A of Figure 2, curve 2 to B, and curve 3 to C*

more water the change becomes less rapid at low voltages as shown by the lower curves. At length, a degree of dryness is reached at which the current no longer changes greatly with voltage unless the voltage is considerably increased, and the voltage necessary to cause it to increase becomes higher as additional water is removed. Removal of this additional water does not noticeably change the conductivity at low voltages. The voltage at which the current increases is believed to be a measure of the energy required to ionize in some manner the water strongly bound to cellulose.

The curves in Figure 2 show the conductance observed when the voltage is applied for one minute. If a direct current voltage is applied for longer times, the conductance progressively changes with time in a manner dependent upon the moisture content. If the cellulose is very wet (A, Figure 2) the current decreases slowly with time (Curve 1, Figure 3), probably as a result of electrolytic action. At lower moisture contents (B, Figure 2) the current increases with time (Curve 2, Figure 3), to a value which in some cases causes heating and eventually destruction of the dielectric. At still lower moisture contents (C, Figure 2) the current falls with time (Curve 3, Figure 3) in the normal manner for dielectric polarization. This phenomenon may prove to furnish a very delicate measure of the degree of dryness, especially when the moisture content is so low that it is determined only with difficulty by other means. Examples of all these various kinds of behavior have been found in certain types of electrical equipment used in the telephone system.

In relatively wet cellulose, the electrical conduction process closely resembles that in electrolytic solutions.* It consists largely of the movement of ions in the aqueous solutions of water-soluble impurities held in pores and adsorbed on surfaces. When cellulose is dried the nature of the conduction process changes, as can be seen from the voltage-current relationships plotted in Figure 2. For comparatively wet cellulose, the upper curves show that the current increases rapidly with voltage applied. With the removal of

*Record, *April* 1929, *p.* 305; *September* 1933, *p.* 8.

A High-Speed Level Recorder for Acoustic Measurements

By E. H. BEDELL

Acoustical Research

FOR many years the oscillo-graph has been available for recording or making visible rapid variations in electric current. Used with a microphone, the oscillograph has also been valuable in studying the wave forms of sound. A knowledge of wave forms, however, is of secondary interest for many purposes; what is wanted is a record of the intensity level of the sound as it varies in pass-ages of speech and music. Although in-tensity level may be determined from a record of wave form, it is not easy to determine it with any accuracy over a range greater than twenty or thirty db, while for some acoustic studies it is desirable that the record cover a range of at least sixty db. To make this possible a level recorder has recently been developed in these Laboratories which records levels on a logarithmic scale over a range of ninety db. One of its important features is the high rate of change in intensity level that it is able to record. Other level recorders have been de-veloped recently but they do not ad-mit either so wide a range in level nor so rapid a change.

This new recorder consists essen-tially of an amplifier and a rectifier, and potentiometers by which the out-put of the rectifier is automatically held constant while the input power changes. The potentiometers are grad-uated logarithmically so that each step in their setting produces the same db change in gain of the ampli-fier. The position of the potentiom-eter arms is thus a measure in db of the change in gain required to hold the rectifier output constant, and is thus also a measure of the change in

level of the input. The position of the potentiometer arms is recorded on a moving tape so that a continuous record of the level is obtained.

A constant-speed motor drives the potentiometer arms in unison through either of two clutches. The motor is connected to the driving part of the clutches through bevel gears so that one clutch rotates in one direction and the other, in the other direction. When neither clutch is energized the potentiometer arm remains stationary, and with one clutch operated the potentiometer is moved to increase the gain of the amplifier, while with the other clutch operated, the rotation decreases the gain. A schematic diagram of the arrangement is shown in Figure 1.

Each of the potentiometers have sixty contact blocks and thus sixty steps. On one potentiometer each step makes a change of one db, thus giving an overall change of 60 db. The steps

Fig. 2—*Schematic of rectifier circuit showing method of operating the clutches*

on the other give each a ½ db change —thus providing an overall range of 30 db. Switches are provided so that either or both of the potentiometers may be used, thus giving a range of 30 db in half db steps, of 60 db in one db steps, or 90 db in 1½ db steps. Although these ranges are entirely adequate for most work, the potentiometers are constructed so that they may be removed and replaced by others of different ranges.

A colored paper with a white wax coating on one side is used for the record, and a stylus which cuts through the wax traces out the curve of level changes. The record is thus a dark line on a white background, which is easily photographed if desired. The paper is an inexpensive standard commercial product, and the record made is permanent. The paper runs over a curved guide with a radius of curvature equal to the length of the stylus arm. The guide is placed slightly above the plane formed by the paper driving roll and a secondary guide so that the paper is held snugly against the
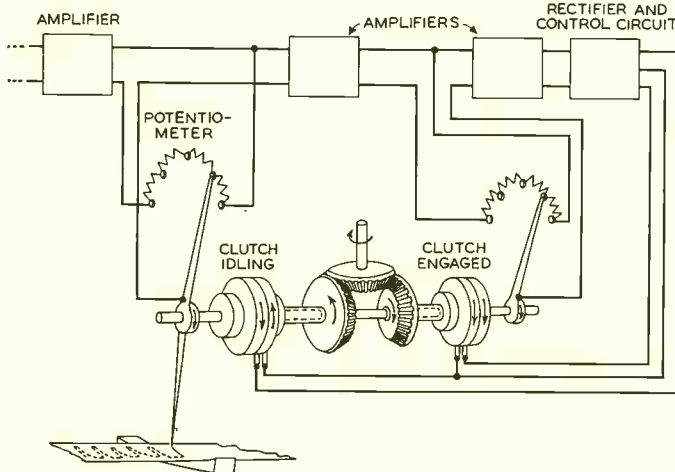

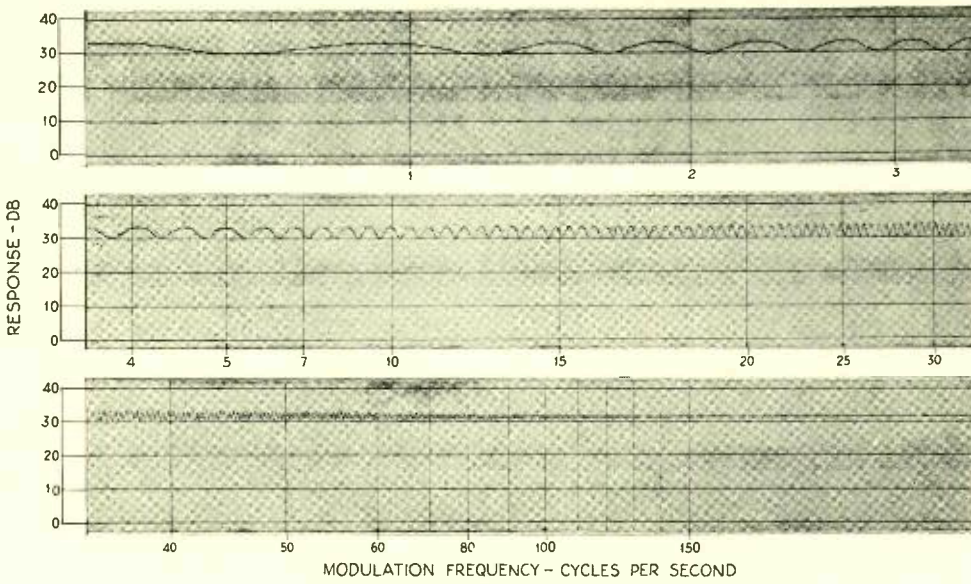Fig. 1—*Simplified schematic of high-speed level recorder*

Fig. 3—*A calibration shows that the recorder will faithfully follow 3 db changes occurring at the rate of sixty per second*
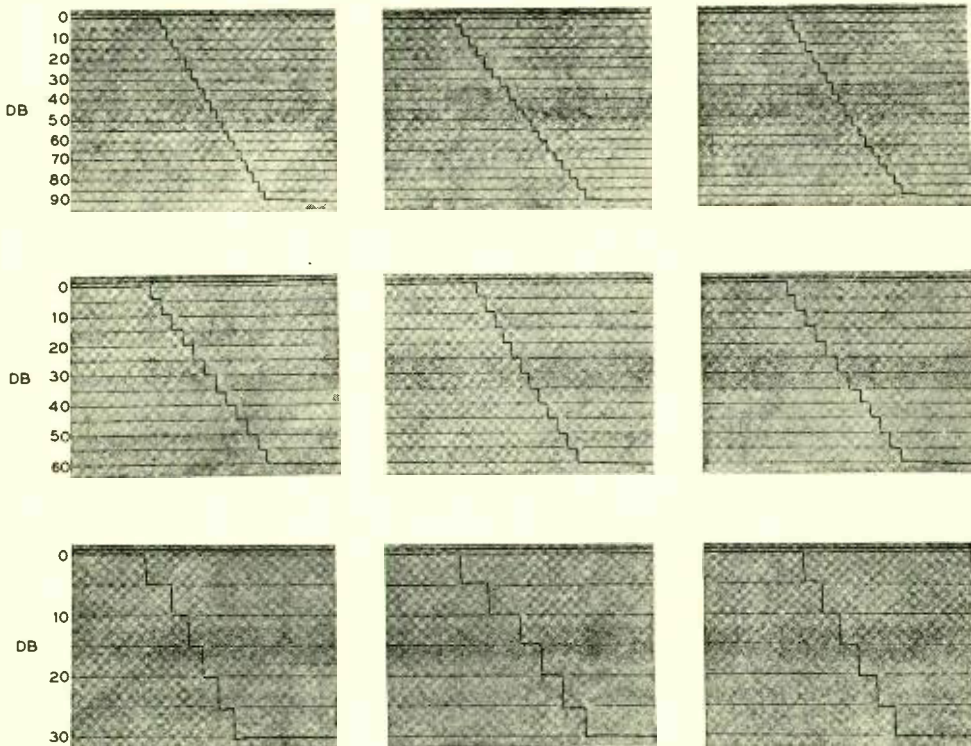

Fig. 4—*A calibration of the three potentiometer ranges in steps of 5 db: left, 20 cycles; center, 1000 cycles; right, 15,000 cycles*
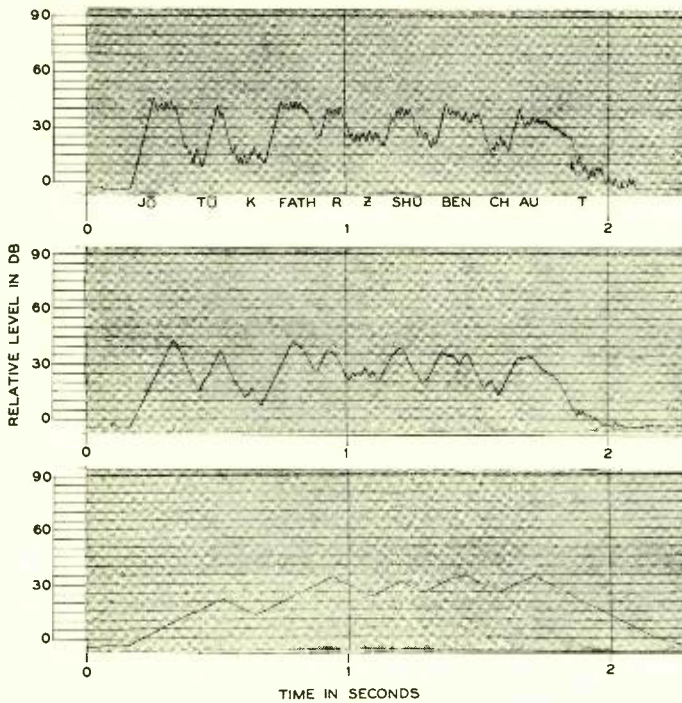
Fig. 5—*The effect of changes in the rate at which the gain is varied is to modify the time over which the level is averaged. Upper curve at 560 db per second, middle at 140 db per second, and lower at 70 db per second*

concave side of the guide. Four speeds, ranging from three inches per second to a little less than three inches per minute are provided for the paper. Its width is 2¼ inches and the maximum stylus deflection is two inches so that the three intensity scales give 15, 30, or 45 db per inch. A marker placed just before the stylus may be employed to trace horizontal lines on the tape to make it easy to read the levels recorded.

Current from the rectifier is employed to energize the clutches by the circuit arrangement shown schematically in Figure 2. Here L_1 and L_2 represent the two clutch coils, and V_1 and V_2 are copper-oxide rectifiers conducting in the directions indicated by the arrows. When, due to changes in input level, the rectifier current i_1

becomes less than $E_3 \div R$, current will flow through L_2, and the potentiometers will be moved to increase the gain. When the rectifier current becomes greater than $(E_2 + E_3) \div R$, current will flow through L_1, and the potentiometers will be operated to decrease the gain. Between these two values of current neither clutch is operated. This range for which neither clutch is operated may be adjusted by controlling the value of E_2, and can be reduced to zero. If it is made smaller than the change in gain produced by one step of the potentiometer, however, the system will oscillate, so that in practice E_2 is made slightly larger.

Two of the primary requirements of such a level recorder are that it be able to follow faithfully the rapidly varying levels. Its performance in these two respects is shown in Figures 3 and 4. In Figure 3 the input was a 1000-cycle current modulated at a continuously increasing frequency over a range of 3 db. It will be noticed that up to a modulating frequency of about 60 cycles per second the record faithfully reproduces the input. Above 40 cycles the amplitude drops off but the recorder indicates the modulating frequency faithfully up to well over 150 cycles per second. Figure 4 shows a calibration of the three level ranges of 30, 60 and 90 db. For each, the input level was changed in successive 5-db steps
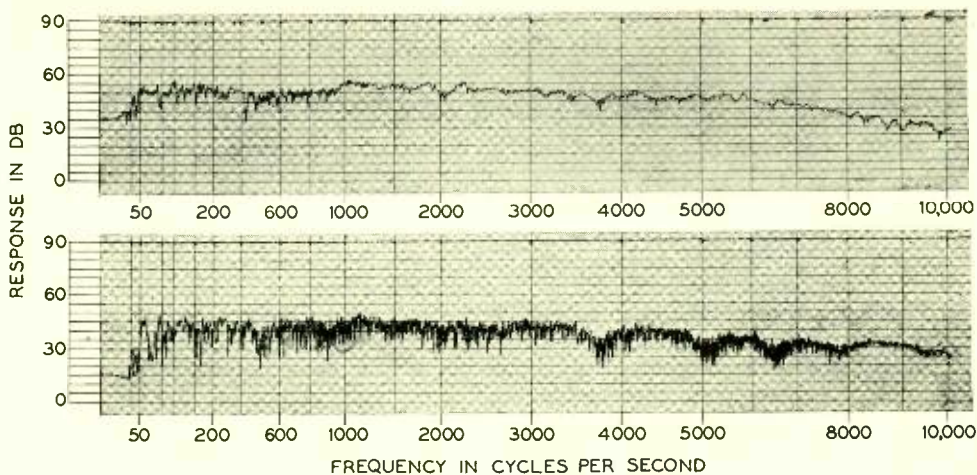
78

Fig. 6—*Response curves of loud speaker obtained with level recorder: upper curve with microphone two feet from loud speaker, and lower curve at eight feet*

over the full range, which the recorder faithfully followed.

The motor that drives the tape also drives the two clutches through another chain of gears. The gears of this drive may be changed independently of those driving the tape, which allows the maximum rate at which level variations are recorded to be changed. This rate of change in level depends also on the combination of potentiometers employed and may be varied from 10 to 560 db per second. Which speed is selected depends on the use to which the recorder is being put at the time. Possibilities in this respect are indicated in Figure 5, which shows a graph of the sentence "Joe took father's shoe bench out" recorded at three different speeds of gain change. The upper curve, employing the maximum speed of level change, shows how the recorder may be employed to record the syllabic power of speech, while the lower curves, taken with a much slower speed, show how the power may be averaged over longer time intervals.

The curves of Figure 6 illustrate the use of the recorder for plotting the response-frequency curves of loud speakers or microphones. For the upper curve the microphone was placed about two feet from the loud speaker, for the lower curve about eight feet. The effect of the greater ratio of reverberant to direct sound is plainly evident in the greater irregularities of the curve.

The appearance of the recorder is shown in the photograph at the head of this article. The amplifier, the mechanical system, and the rectifier which furnishes the power supply, each occupy one of three cases, which are interconnected with plug-in cords so that the instrument is readily portable. The input transformer of the amplifier has a low impedance winding designed for use with the moving coil microphone, but a high impedance input terminal is also provided to allow of other uses. A manual gain control is furnished in addition to the automatic potentiometer control so that the curves may be brought to a convenient position on the tape. This instrument has been used successfully for many recent acoustic studies, and should find wider use in the future.
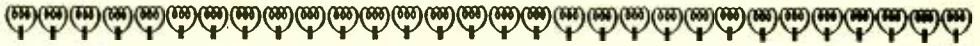
At the America's Cup Races

DURING THE recent International Yacht Races off Newport, the United States Coast Guard made effective use of a high-power announcing system to patrol the course and issue instructions to the spectator craft. The equipment was installed and used on the U. S. Coast Guard cutter *Tampa* under the supervision of D. T. Bell. At various times during the races A. F. Price, H. C. Curl and H. F. Hopkins were on board to observe the operation of the system.

In the installation on the *Tampa* the transmitter and a volume indicator were mounted on a small panel attached to a forward window frame on the bridge; the two associated amplifier bays and the motor-generator were located in the chart room immediately below the after part of the bridge and the loud speaker was mounted on a wooden platform placed on the flying bridge.

A clip-type mounting was provided for the transmitter and 20 feet of cord was attached so that the transmitter could be used at any desired position on the bridge.

The loud speaker mounting normally allows for a 330 degree rotation in the horizontal plane and a 60-degree rotation in the vertical plane. The position of the loud speaker on the flying bridge was such that for practical purposes there was no obstruction to the sound waves in a region of approximately 120 degrees in the horizontal plane on either side.

In performance the loud speaker is capable of maximum sustained output of approximately 500 watts of sound. The maximum conversion efficiency is approximately 60 per cent.

During preliminary tests in Newport harbor with the system operating at one-third rated capacity, instructions were given to the rest of the ships in the patrol force. These boats were at various distances up to a maximum of 1500 yards from the *Tampa* and all received their instructions correctly with the exception of one boat 800 yards directly astern.

On the day before the first race, the patrol fleet consisting of five Coast Guard cutters in one line and one cutter and four destroyers in another line performed practice maneuvers preparatory to the races. During these the announcing system was used to instruct two patrol boats, representing the racing yachts, and the cutters in the line with the *Tampa*. The commands were heard on the patrol boats for all distances up to 1500 yards and in some cases at a greater distance.

On the day of the first race, several hundred boats were in the spectator fleet and the announcing system aided materially in keeping them in their proper position. Good response was obtained for all distances up to about 2000 yards. During the entire series of races the system was used approximately 300 times. On one occasion the command was heard at greater than conversational level on the deck of a ship 5,000 yards away.

Western Electric Announcing System
Directs Traffic at Yacht Races
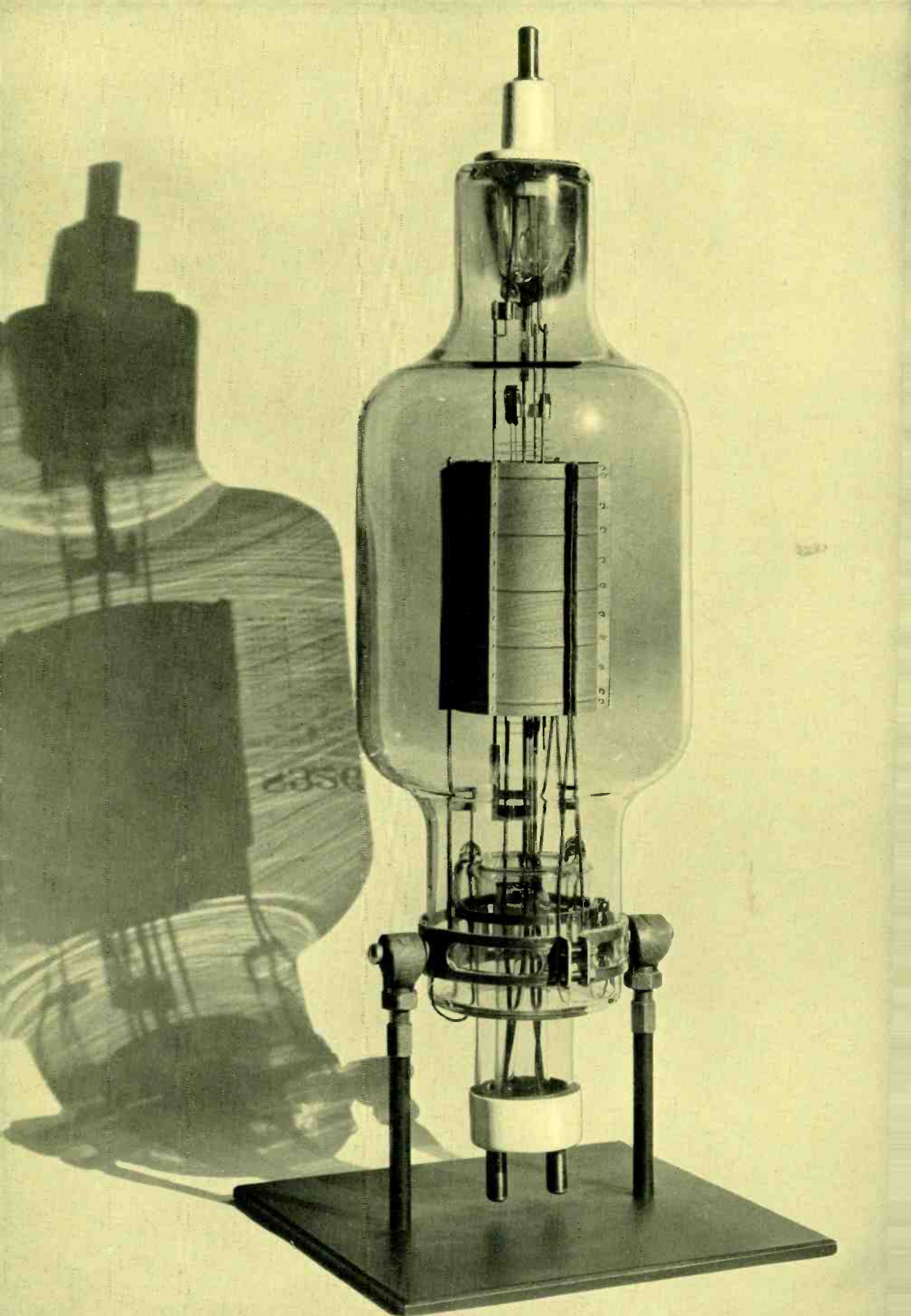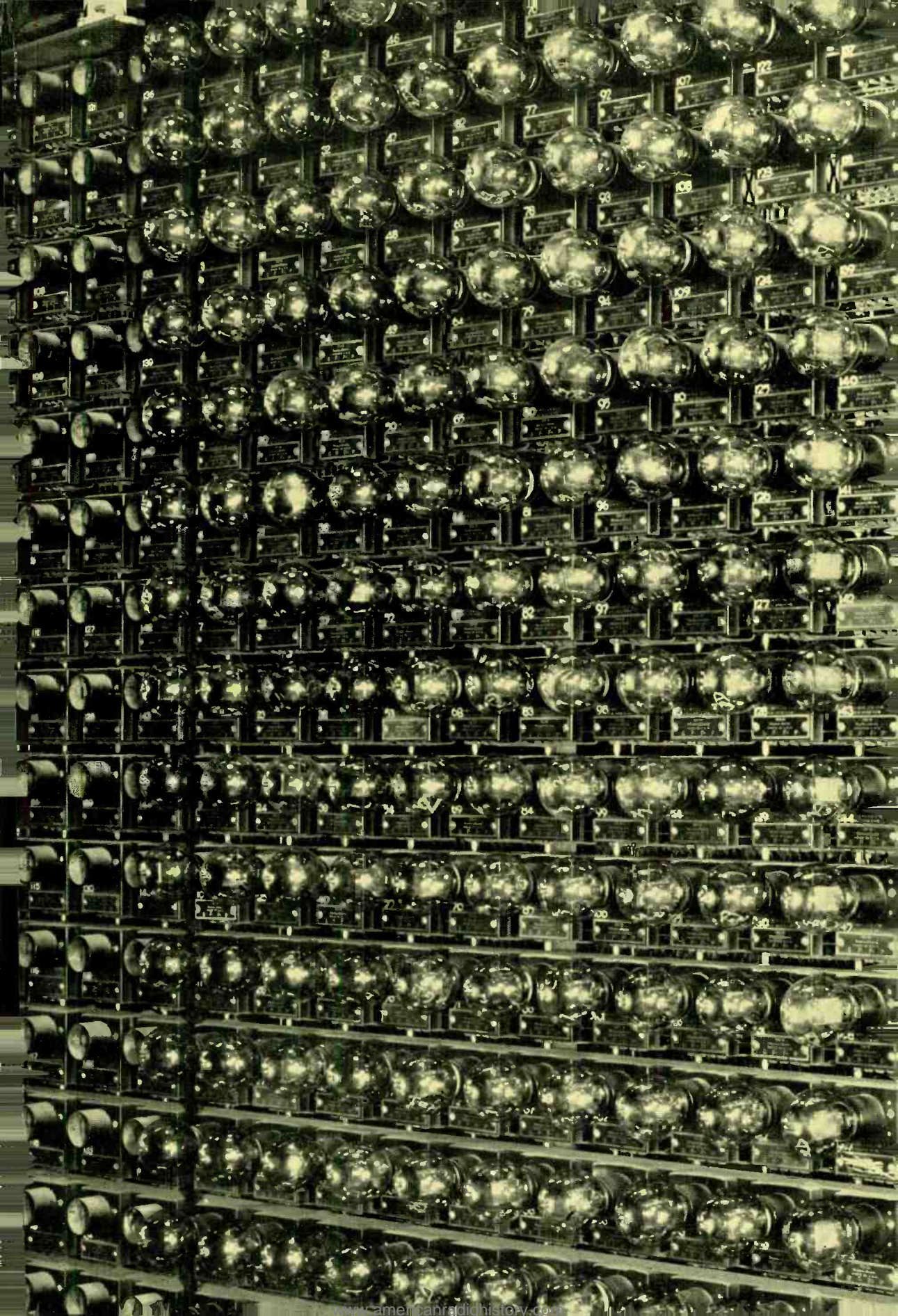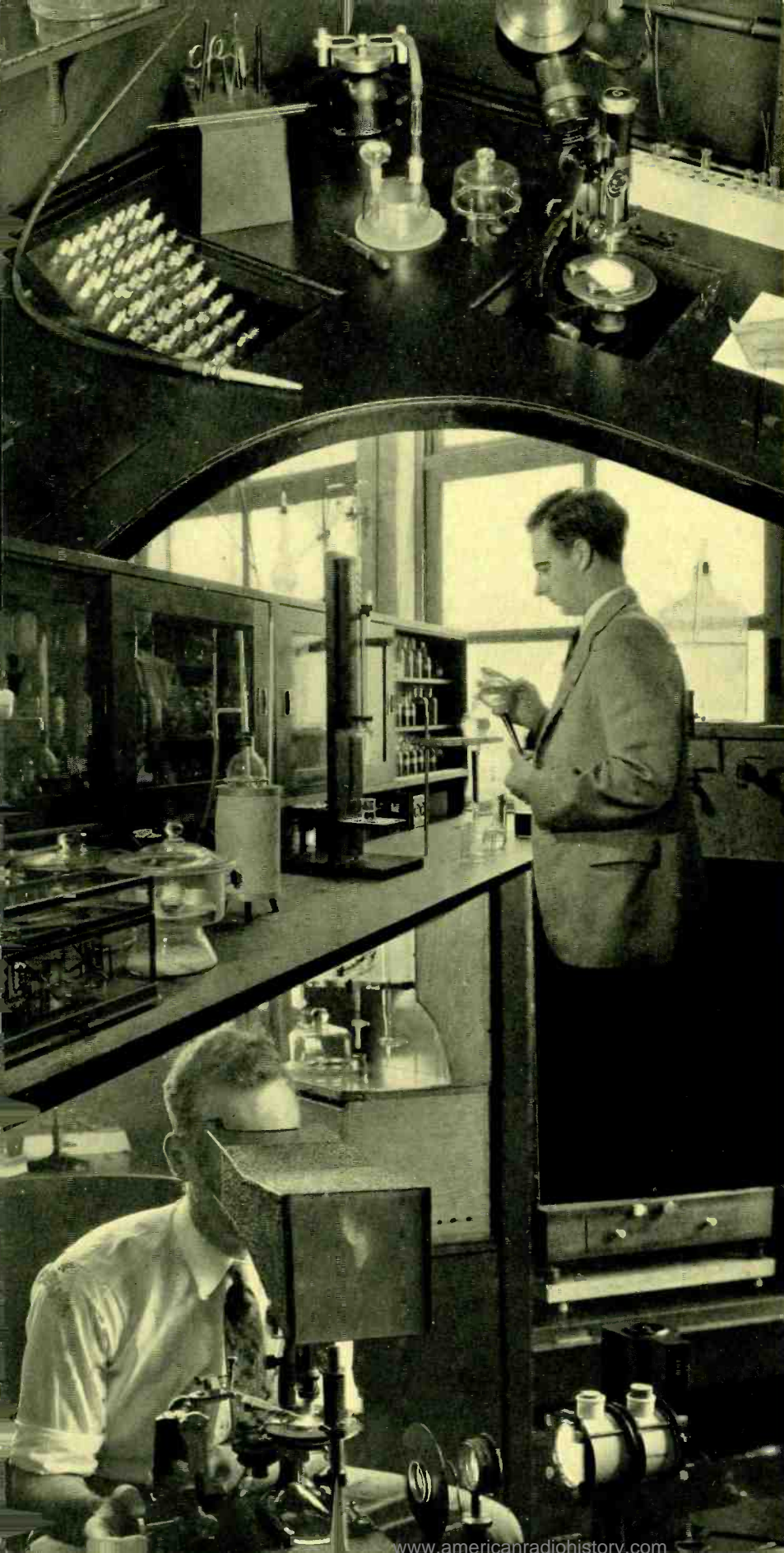
During its short history of about six years, the laboratory for microanalysis and chemical microscopy has become an important adjunct to the development of improved telephone equipment in Bell Telephone Laboratories

Microanalysis

By H. W. HERMANCE
Chemical Laboratories

RECENTLY, when tiny discolorations were found on the surface of a polished silver sheet used in the manufacture of photoelectric cells, contamination with mercury was suspected. To confirm this suspicion, a very small drop of nitric acid was allowed to act for a few seconds on the discolored spot, and then was transferred to a capsule and evaporate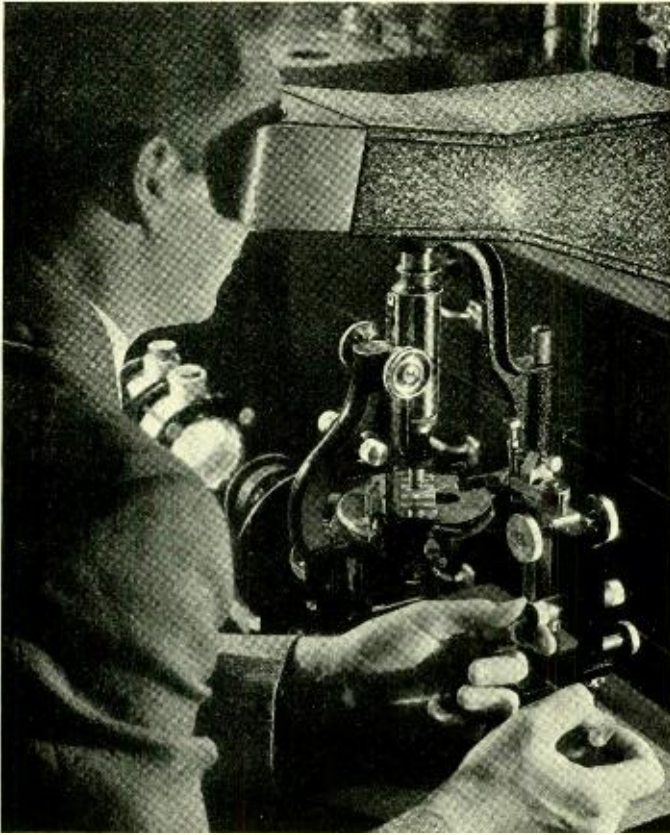d. The residue, redissolved in a small drop of water, was drawn up into a capillary tube containing a little fine copper wire. With both ends sealed, the tube was heated for a few minutes in boiling water, and then one end was opened, the liquid was removed, the open end was drawn out into an extremely fine tube, and the closed end was heated until the glass fused about the copper wire. Under the microscope, minute distilled droplets of mercury were plainly visible in the fine end of the tube when it had cooled.

Innumerable examples such as this could be cited in which microanalysis, dealing with extremely small quantities of materials, is the only satisfactory means available for determin-

ing the chemical constituents of a sample. In many other cases, although a large enough sample is available to permit the use of the older analytical methods, it is faster, cheaper, and more certain to perform a microanalysis. In recent years, microanalytic methods for discovering the nature of the constituents of materials have been extended to offer the same advantages in determining the amounts of the constituents.

The analysis of a platinum-cobalt filament illustrates several typical advantages of the micro methods. In conventional practice, the platinum would be precipitated as ammonium chlorplatinate by adding an excess of solid ammonium chloride. The precipitate would be transferred to a paper filter, washed free of cobalt, and again transferred to a platinum crucible where it would be ignited to platinum sponge and weighed. The

cobalt would be determined by electrolytic deposition from the filtrate. In this procedure platinum may be lost during the transfers of precipitate. Because of the large excess of ammonium chloride required to maintain the insolubility of the ammonium chlorplatinate, contamination by impurities and dust unavoidably present in the reagent is very likely. During the long filtration and washing, atmospheric dusts are likely to be introduced. The electrolysis of the filtrate is complicated by the large concentration of ammonium chloride, and the results tend to run high. For a sample as small as ten or twenty milligrams, this procedure would be entirely impracticable.

By refinement and specialization of apparatus, and better choice of reactions, the micro method avoids most of these difficulties. It requires only a few milligrams of sample, dissolved in a five-cubic centimeter microbeaker which has been weighed together with an inverted filter. By adding caesium chloride and alcohol, the platinum is precipitated; the liquid is drawn off through the inverted filter into a second weighed beaker; the highly insoluble precipitate of caesium chlorplatinate is washed and dried, and the precipitate and apparatus are weighed together to determine the platinum. The liquid in the second beaker is neutralized, the cobalt is precipitated as the anthranilate, and the washed

Fig. 1—In a microsublimation chamber designed in these Laboratories, small quantities of volatile solids can be sublimed at controlled temperature and pressure directly onto a microscope slide
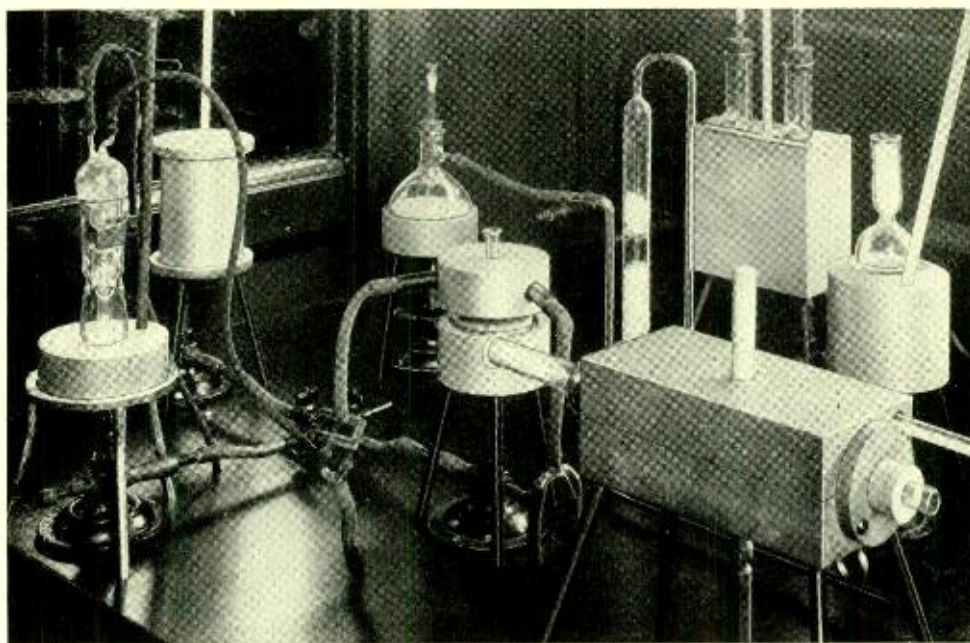
Fig. 2—The heat-treatment and conditioning of materials can be conducted much more accurately and economically on a small than on a large scale

and dried precipitate and beaker are weighed as before to determine the cobalt. Here the error has been reduced along with the size of the apparatus, the amount of manipulation, and the solubility of the conversion products. Moreover cobalt anthranilate has about six times the weight of the cobalt in it. The expense of caesium chloride would prohibit its use on a larger scale.

The term "microanalysis" is used to describe a variety of such methods because of their mode of departure from classical techniques. In common these methods seek to attain their goal by reducing the scale of operations to a degree consistent with the small quantities of material frequently handled. To this end, the analyst's ability to make observations is augmented by instruments such as the microscope and microbalance, by specific and highly sensitive reactions, and by the

formation of conversion products of high molecular weight.

The microanalytic laboratory thus presents a sharp contrast to the usual chemical laboratory. Specialized apparatus, often of greatly reduced size, takes the place of the relatively large beakers, flasks, test tubes and the like, developed many centuries ago for synthetic work and since used almost unchanged for analytical work as well, without regard for their ineptitude to it.

Naturally the first efforts along these lines were made in fields where the necessity of working with little more than traces of a material has always been a problem. Specific reactions were carried on under the microscope to identify the components of plant cells and to detect poisons in extracts of cadaverous materials. With progress in the technical trend of commercial production, refinement of
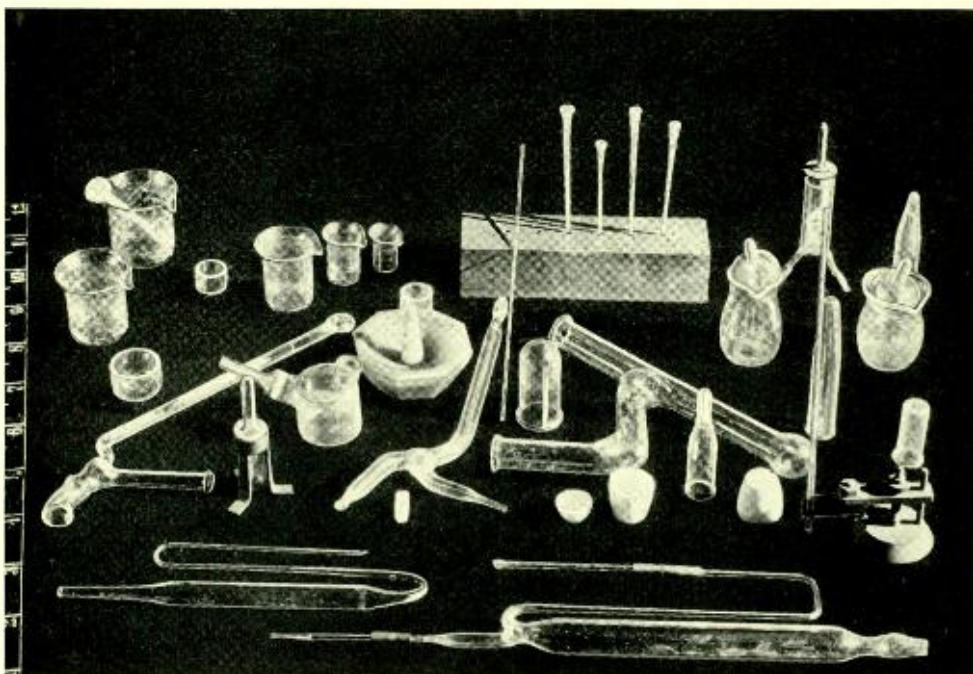
Fig. 3—Much of the glass and porcelain apparatus used in microanalysis departs radically in form and size from standard chemical apparatus

analytical technique was demanded in industry also, and these methods began to be applied in Europe to determine the nature of newly formed products and to gain knowledge of the mechanisms of particular processes. The installation of a completely equipped microchemical laboratory at West Street about six years ago constituted a pioneer step in the direct application of micro-technique, in its broadest sense, to engineering problems in this country.

A great many microanalytic investigations can be performed with apparatus similar to that in standard chemical use, built on a reduced scale and supplemented by the microscope and the capillary. Indeed these two implements suffice alone for many qualitative analyses, as in the case of the mercury detection already described. A drop of potassium mercuric

thiocyanate, for example, applied with a capillary to a drop of a solution containing several metals gives a precipitate from which, under the microscope, the experienced analyst can often tell the nature of the mixture from the known crystal habits of various combinations of metals. Similarly, drops of salt solutions can be evaporated or volatile solids can be sublimed directly onto the microscope slide, and the components of the deposit can be identified by their crystalline forms and optical properties under the microscope.

The last mentioned process, that of sublimation, in which a solid is condensed from the vapor without passing through an intermediate liquid state, is rarely employed in ordinary analysis but has proved of great service in microanalysis. A few thousandths of a milligram of a volatile

84

crystalline solid may be separated in this way from a large bulk of inert material, in a condition permitting immediate treatment with reagents. In order to apply this process to dusts and corrosion products, the Microchemical Group of Bell Telephone Laboratories has designed an improved micro-sublimation chamber. The apparatus is so arranged that both temperature and pressure may be regulated. The vapor condenses on a water-cooled microscope cover-glass, and practically all the material is isolated. As little as two thousandths milligram of mercuric iodide, for example, was found to give a deposit of definitely recognizable crystals.

Quantitative microanalyses also can often be performed by simple means. The amount of mercury collected in the capillary, in the analysis of the stain on the silver plate, could have been readily determined by centrifuging until the tiny droplets coalesced into a single drop, and then measuring the diameter of that drop by microscopic projection. Similarly, the analysis of a minute amount of gas can be carried out by measuring the shrinkage in diameter of a single microscopic bubble as the absorption reagents in which it is immersed are changed.

A striking example of the simplicity and ingenuity of many micro-quantitative techniques is Barger's method for determining molecular weights. Two solutions, one known, the other containing the unknown, are placed in a capillary with a small air bubble separating them. The ends of the capillary are sealed, and the lengths of the two liquid columns are measured. As the column lengths slowly change, the measurement is repeated at intervals until they become constant. When this occurs, the vapor pressures

of the two solutions are identical, and since vapor pressure is a function of the molar concentration, the latter must also be the same in each solution. From the change in the volumes of the two solutions, the original weight concentrations, and the molecular weight of the known substance, the molecular weight of the other can be calculated.

Other microanalytic investigations are greatly facilitated by special apparatus, and a variety of ingenious devices have been perfected for such purposes. One of the most interesting is a cell designed by H. Brenneis, permitting the electrolysis of a single drop of solution and simultaneous observation of the electrode surfaces under the microscope. The electrodes

Fig. 4—With this electrolytic cell, as little as one milligram of metal may be precisely determined

are formed by encasing closely spaced platinum wires in glass which is then cut perpendicularly to the wires and polished, to expose cross-sections of the wires. The drop to be electrolyzed is placed on the polished glass surface, and the portion covering the platinum areas is observed through the microscope. In this way a thousandth milligram of copper may readily be recognized, and as little as a tenth of this amount of zinc has been detected with the use of a previously coppered cathode.

To the field of quantitative microelectrolysis these Laboratories have made a contribution in the form of cells which permit the determination of metals such as copper, zinc, nickel, lead, cadmium and tin, using five milligram samples, with the same accuracy as that attainable in ordinary analyses on one-half gram. One of these cells, designed for the analysis of extremely dilute solutions, permits the recovery of one part of copper, zinc, or lead in a hundred million parts of water, and is particularly useful in isolating minute quantities of heavy-metal impurities in such metals as aluminum and nickel, and in examining waters which have been used in corrosion experiments.

A phenomenon familiar to all, but not applied to analysis until its value in micro-work was recently demonstrated, is the production of "Schleiren," or refraction lines, when a stream of one liquid passes into another liquid of different optical density. A few tenths of a cubic centimeter of one liquid is placed in a flat optical cell, and the other liquid is slowly introduced below the surface of the first through a capillary orifice. The refraction effects are observed through a horizontally mounted microscope under controlled illumina-

tion. When one of the liquids is known, such observations can be used to determine both the refractive index and the specific gravity of the other. So sensitive is the method that a difference of one ten-thousandth in the refractive indices is detectable.

Variations in the composition of small metal parts require independent analyses of the parts, and thus the use of micro-methods. The compositions of single relay contact points, weighing from five to ten milligrams, have been quantitatively checked when excessive deterioration was noticed. The gold plating on small areas of handset transmitter parts—only a few tenths of a milligram of gold—has been precisely determined to check the uniformity of the coating. Vacuum tubes and photoelectric cells have also furnished their micro-analytic problems. In studying the distribution of caesium on the various surfaces of the photoelectric cell, the analyst had to deal with no more than a milligram and a half of caesium at one time. Single filament wires have been analyzed to determine the thoria in tungsten filaments, and the copper, iron, silicon, and manganese in nickel wires.

In studying variations in composition between very thin layers of materials, not only micro-analytic but micro-collective methods must be employed. Sheets of an iron-cobalt alloy were observed to change in magnetic properties after rolling to a thickness satisfactory for receiver diaphragms, and it was suspected that the surface lost iron through oxidation and subsequent mechanical removal. By using pure silica abrasive, about five thousandths millimeter of metal was removed from the surface; the metal was then extracted from the abrasive and the iron-cobalt ratio was

determined micro-chemically. A similar technique has been used to determine the migration of copper through the tin on tinned copper wire, and to study the alloy layer formed between the zinc coating and the iron base on galvanized and sherardized parts.

In studying central-office dusts and their effects on dial switching apparatus, the problem of micro-collection has been especially severe, and the Microchemical Group has developed a number of special devices for the purpose. Especially notable is an adaptation of the "impinger," which is used to remove dusts from the extremely localized area represented by a single relay contact point. The particles are picked up by suction and projected at high velocity against a microscope slide coated with an adhesive. In the ways described and in many more the maintenance of micro-analysis as a continuing and special function in telephone engineering has long since proved justified.
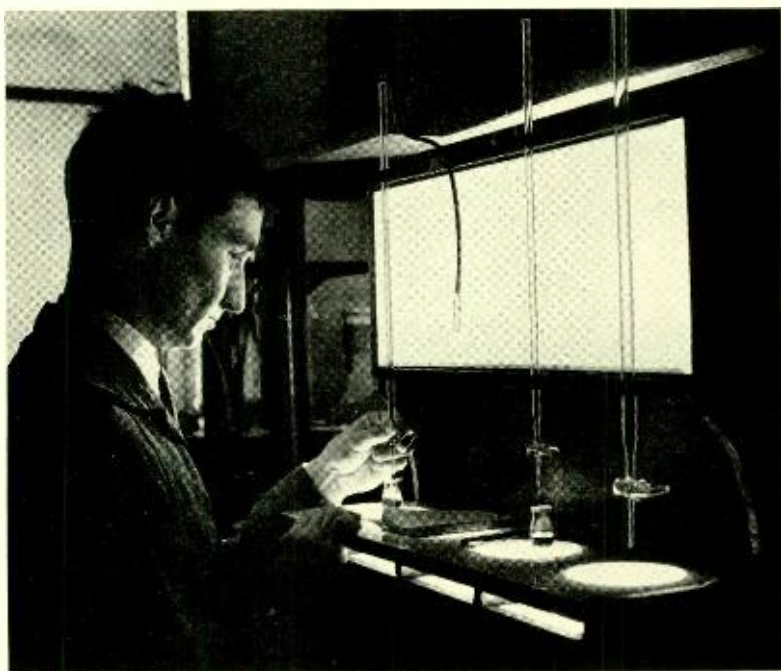

Fig. 5—A small quantity of a solution is being titrated by D. O. Westbrook with a microburette mounted on a specially illuminated stand which facilitates the observations of the end-point of the reaction and the reading of the burette

Gas-Filled Thermionic Rectifiers

By S. B. INGRAM
Vacuum Tube Development

THE introduction of power tubes into radio transmitting systems during the last decade brought a demand for sources of high potential direct current to supply anode voltage. High-vacuum tubes, themselves, have proved quite satisfactory for this purpose, but because of certain advantages of convenience and efficiency, thermionic rectifiers of the mercury-vapor type are gradually replacing them.

The form of the current-voltage characteristics of a vacuum and of a mercury-vapor rectifier show how markedly different are the properties of these two types of devices. The current-voltage characteristic of a 237A rectifier, a high-vacuum, water-cooled type, is shown in Figure 1, while the corresponding curve for a 266A mercury-vapor hot-cathode tube, which is now replacing the former in many installations, is shown in Figure 2.

In the high-vacuum rectifier the presence of electron space-charge between the filament and plate creates a

potential barrier which the electrons must surmount, making it necessary to apply plate potentials of the order of several thousands of volts to draw plate currents of a few amperes. This, of course, results in the dissipation of a large amount of power in the anode, and to carry away the excess energy, water-cooling of the plates has been introduced in all the larger tubes. This energy loss within the tube represents, of course, a considerable loss in the efficiency of the rectifier.

The presence of gas in mercury vapor rectifiers, on the other hand, gives them very different properties. The electrons emitted from the filament collide with mercury atoms and ionize them. The ionization process consists in the removal of an electron from the neutral atom thus giving a free electron and a positively charged ion. The positive ions neutralize the electron space charge and thus destroy the barrier which made high plate voltage necessary in the vacuum tube. As a result the potential drop across a mercury vapor rectifier is practically independent of plate current and has a value of only some 10 or 20 volts. This low drop results in small energy dissipation in the tube and a corre-
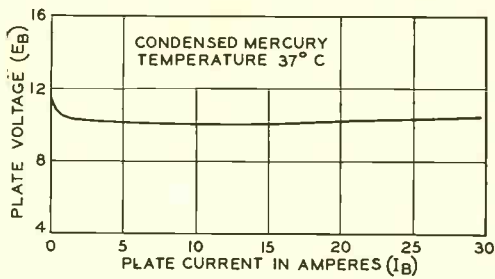
Fig. 2—*Characteristic of 266A mercury-vapor rectifier*

sponding increase in rectifier efficiency. The low plate loss also obviates the necessity for water-cooling the anodes, and thus makes the gas tubes somewhat simpler to operate than the large vacuum tubes.

Another advantage of the gas-filled rectifier compared to the high-vacuum type is the better "regulation" of the rectifier output. In other words, the voltage output of the rectifier is more nearly independent of the direct current drawn. In vacuum-tube rectifiers the tube drop is large and increases with the current, thus causing the output voltage to fall off as the load increases. With gas-filled rectifiers, on the other hand, the tube drop is small compared with the total applied voltage and substantially independent of current, and as a result the output voltage is more nearly independent of the current.

The introduction of gas into a vacuum tube greatly changes the conduction phenomena within it, and the design of the tube, therefore, must be approached from a widely different angle. A consideration of the filaments used in vacuum and gas-filled tubes will illustrate this point. In a vacuum tube the filament or cathode must always be of simple geometrical shape: a straight wire, or a V or W shape arranged in such a way that the field of the plate can penetrate readily
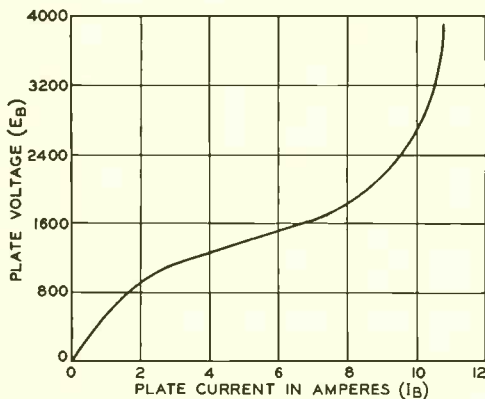
Fig. 1—*Characteristic of 237A vacuum rectifier*

to all points on the filament. A typical example is shown in Figure 3. If this is not done, if, for instance, the cathode contains a fold or cavity of some sort, the electrons within this cavity are, to a great extent, electrostatically shielded from the field of the plate, and so cannot emerge to contribute to the plate current. In a gas-filled
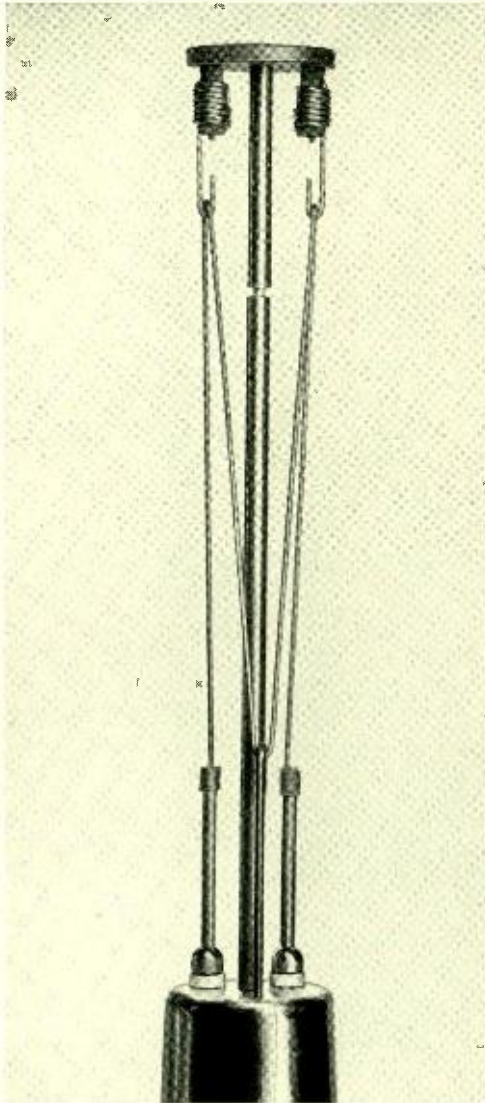

Fig. 3—The filament of a vacuum tube is of simple geometrical design, usually a V or a W as in this 237A tube

tube, on the other hand, the geometry of the cathode is not restricted by any such limitation. The space between the anode and cathode is filled by a swarm of electrons whose space charge is neutralized by a practically equal number of positive ions. This cloud of charged particles mixed with neutral gas molecules is known as the "plasma" and fills the whole tube. The plasma completely surrounds the filament and, if the latter is of complicated geometrical shape, penetrates into the folds and recesses, making it possible to extract electrons from them. For this reason one is at liberty in the gas tubes to fold a filament back and forth in the form of a bellows, thus obtaining a large emitting surface concentrated in a relatively small volume as shown in Figure 4. This greatly increases the efficiency of the filament with respect to power consumption by reducing the loss of heat by radiation. This heat efficiency is further increased in some tubes by surrounding the filament with a bright metal heat shield open on the side facing the anode. These various heat saving devices increase the emission efficiency of the cathode by several fold.

Of the various electron emitting sources common in vacuum tube practice, the oxide-coated filament has proved the most suitable in tubes with gas filling. Thoriated tungsten is not satisfactory because its high emission efficiency depends upon the presence of a monatomic layer of thorium on tungsten, and this delicate layer is more susceptible to destruction by positive-ion bombardment than is the more rugged oxide coating. Pure tungsten proves to be unsuitable on account of its low electron emission efficiency.

The 237A vacuum rectifier tube

which has a pure tungsten filament capable of supplying 10 amperes current has a power consumption of 1220 watts. The electron emission efficiency is therefore about 8 milliamperes per watt of filament power. The 266A mercury-vapor rectifier, on the other hand, which will supply 20 amperes of current, consumes only 300 watts, the emission efficiency being about 67 milliamperes per watt.

In the anode element of the gas rectifier tubes there is again a sharp contrast with the corresponding element of a vacuum rectifier tube. In a vacuum rectifier tube the anode always surrounds the filament, and is placed symmetrically with respect to it so that its field may be as uniform as possible over the cathode surface. In the gas tubes, however, since the plasma fills the whole tube, the anode is restricted by no such requirement. It is therefore usually brought into the bulb at the opposite end from the filament and is separated from the latter by a space of one or two inches. This construction has the advantage that a long glass path gives high insulation resistance between the anode and cathode during the non-conducting portion of the cycle when a high inverse voltage is applied to the tube. To avoid high voltage gradients in the gas, which might give rise to disruptive discharge in the inverse direction, sharp points and corners are avoided on both the cathode and anode structures. So far it has been possible to design the larger rectifiers in such a way that voltages as high as 20,000 volts may be safely applied without "arc back," as breakdown in the inverse direction is called.

In small rectifiers, the energy dissipated in the anode is so slight that the temperature is not raised high enough to cause thermionic emission, but the
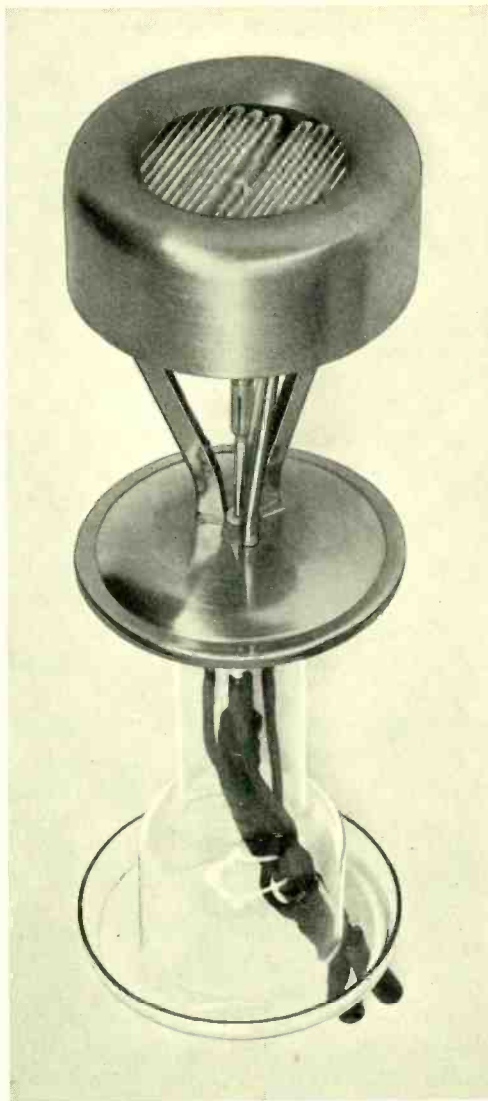

Fig. 4—The filament of a mercury-vapor tube may be folded back and forth to obtain a large area as in this filament of a 266A tube

larger sizes, when working near their maximum current rating, must absorb and reradiate a considerable amount of heat. If active material from the cathode should vaporize and deposit on the anode, and the latter should come to a visible red temperature, thermionic emission might be-

come sufficient to cause "arc back." This temperature is kept within safe limits by making the anodes sufficiently large, and by employing graphite, which has a very high heat emissivity, as the anode material.

To compare the efficiencies of the vacuum and mercury-vapor rectifiers, it will be instructive to consider an actual system where the latter type of tubes have replaced the former. In the 50 kw broadcast transmitter, requiring a dc power supply of 12 kw amperes at 17.5 kilovolts, six 266A mercury-vapor rectifiers have replaced the six 237A vacuum rectifiers formerly in use. The cathode of the 266A tube requires only 300 watts, giving a total cathode heating power of 1800 watts, while 7300 watts are required by the filaments of the water-cooled type. The total anode power dissipated by the gas-filled tubes is about 350 watts compared to roughly 20,000 watts that must be carried off by the much more complicated water-cooling system of the 237A tubes. The power supply efficiency of the newer equipments has thus been increased from 88% to 99%.

One of the important factors in the operation of these tubes is the mercury-vapor pressure, which is determined by the temperature of the coolest part of the bulb, usually a point near the base of the tube. The optimum pressure is about 5×10^{-3} mm of mercury, and corresponds to a condensed-mercury temperature of about 40° C. The useful operating range of pressure for high voltage rectifiers is from about 1×10^{-3} mm to 5×10^{-2} mm, corresponding to condensed-mercury temperatures of 20° C. and 70° C. respectively. Since the coolest part of the bulb operates somewhat above the temperature of the surrounding air, the air temperature

range will be lower than this, usually by about 15° C. Thus 5° C. to 55° C. would be a typical ambient temperature range. Continued operation below the lower temperature limit will shorten the life of the tubes through destructive positive-ion bombardment of the filament under the higher arc drop which prevails at low mercury pressure. Above the upper limit, due to the increased mercury-vapor pressure, the breakdown voltage is reduced so that the tubes will not stand the high inverse voltages to which they are subjected in most high voltage rectifier circuits.

Rectifier tubes may be filled with gases other than mercury vapor. Mercury happens to be the one chemical element whose vapor pressure at room temperature is in the range suitable for gas discharges, that is, from 10^{-3} mm of mercury to several millimeters. With other gases, dependence must be placed upon the original gas filling to last throughout the life of the tube. Owing to absorption by the metal parts and sputtered deposits on the walls and electrodes, the "clean up" of most gases is quite rapid, rendering them unfit for this use. The rare gases, however, are not so much subject to this difficulty, and it is possible to use them. Argon and neon are the most commonly employed. Even these, however, are absorbed, and it is necessary to fill the tubes to a pressure of several tenths of a millimeter to obtain satisfactory life. At such pressures the breakdown voltage, which determines the magnitude of the alternating potential which can be rectified, is of the order of several hundreds of volts, whereas with mercury at pressures below 5×10^{-2} mm, voltages up to 20,000 can be rectified.

Although rare gases are not satis-

factory for high voltage rectifiers, they have certain advantages for low voltage work, which makes their use desirable in some tubes. When a rare-gas filling is used the gas density is independent of bulb temperature so that such tubes may be operated over a much wider ambient temperature range. Also mercury vapor tubes require from five to fifteen minutes to come to temperature equilibrium and during this time the gradual decrease of tube drop results in a variation of dc output which is quite noticeable in low voltage rectifiers. If this effect is objectionable it may be avoided by using tubes filled with argon or some other of the rare gases.
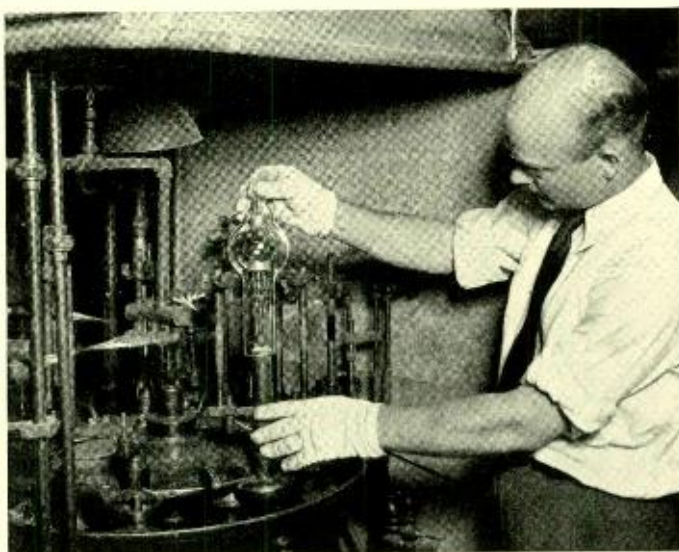
A 267A mercury vapor tube being placed in a sealing-in machine during assembly by C. L. Johnson
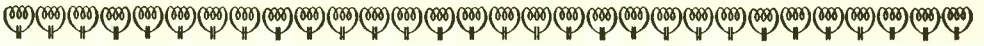
Contributors to This Issue

E. H. Bedell received the B.S. degree from Drury College in 1924 and then spent a year doing graduate work at the University of Missouri. The following year he joined the Laboratories as a member of the Acoustical Research Department. Here his work has had to do mainly with studies of sound absorption and transmission and allied subjects in the field of architectural acoustics.

For the past ten years G. T. Kohman has been engaged in physico-chemical research in these Laboratories. After receiving the B.S. degree in 1920 from the University of Kansas, he went to Yale University to pursue graduate study. In 1923 he received the Ph.D. degree and in September of that year came to West Street. Here he has been occupied with investigations into the mechanism of oxidation of organic substances and with studies of the paper and impregnants used in condensers. He now heads a group devoted to this work.

After receiving the E.E. degree from the University of Minnesota in 1911,

Arthur G. Chapman spent two years with the General Electric Company and then joined the Engineering Department of the American Telephone and Telegraph Company. There, and later with the Department of Development and Research, he engaged in developing methods for reducing crosstalk between communication circuits and evaluating effects of crosstalk on telephone and other services. This work has included the development of transposition systems for open-wire lines, and special design features and apparatus for reducing crosstalk in toll cable, voice frequency and carrier frequency circuits being involved in both cases. Mr. Chapman now heads a group devoted to these investigations, which was transferred to these Laboratories last spring.

H. W. Hermance came to these Laboratories in 1927 with a wide background of experience in chemical analysis. For two years he assisted Dr. Edel in toxicological and criminological work on cases coming before courts in New Jersey, and

E. H. Bedell   *G. T. Kohman*   *A. G. Chapman*

[94]

for a like period he was associated with the Crucible Steel Corporation. Later he spent four years in the Staten Island Works of Procter & Gamble, the last two as assistant to the head chemist, developing analytical methods for controlling the quality of raw materials and products. During most of this period he pursued part-time study, first at Newark Technical School and later at Columbia University, which he still continues. In 1925 he entered the analytical laboratory at the Kearny Works of the Western Electric Company, to conduct analyses insuring that raw materials conform to specification. The microanalytical laboratory at West Street, which Mr. Hermance now heads, grew out of work undertaken by him in the general analytical laboratory to which he transferred from Kearny seven years ago.

S. B. INGRAM received a B.A. degree from the University of British Columbia in 1925, and a Ph.D. in physics from the California Institute of Technology three years later. During the next two years, as National Research Fellow in Physics, he carried on research studies in experimental and theoretical spectroscopy at the University of Michigan. In 1930 he joined the Technical Staff of Bell Telephone Laboratories, where he has been in charge of a group developing mercury-vapor rectifiers, three element gas-filled tubes, and other gas discharge devices.

H. W. Hermance   *S. B. Ingram*
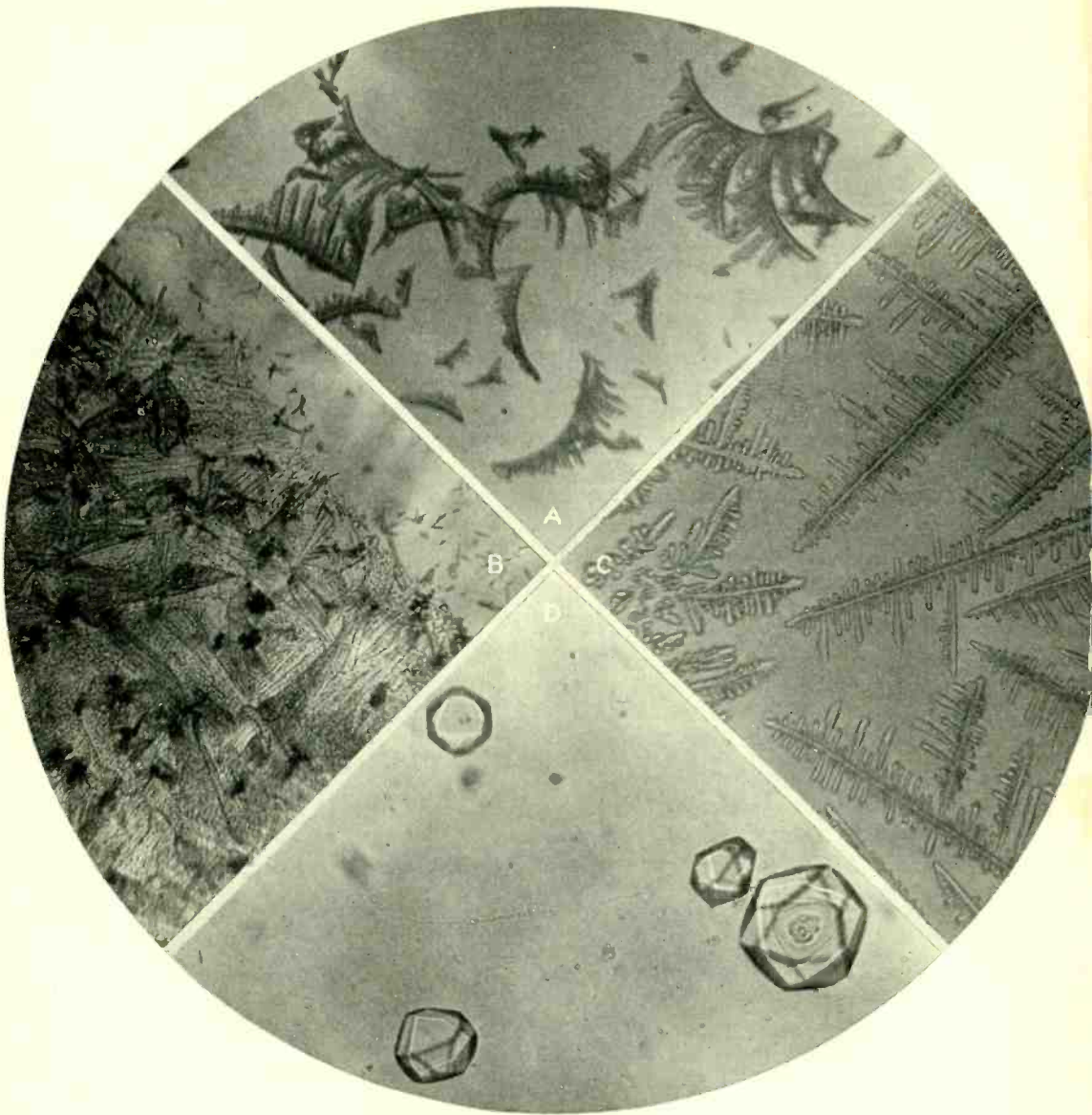
With the aid of the microscope, many substances can be identified by the characteristic crystalline forms which they display when condensed from vapor, or deposited from solution, on a microscope slide. The substances here pictured are (A) zinc mercuric thiocyanate containing a trace of copper which gives the crystals a purple color, (B) dinitrobenzoic acid (sublimed), (C) ammonium chloride (sublimed), and (D) caesium alum