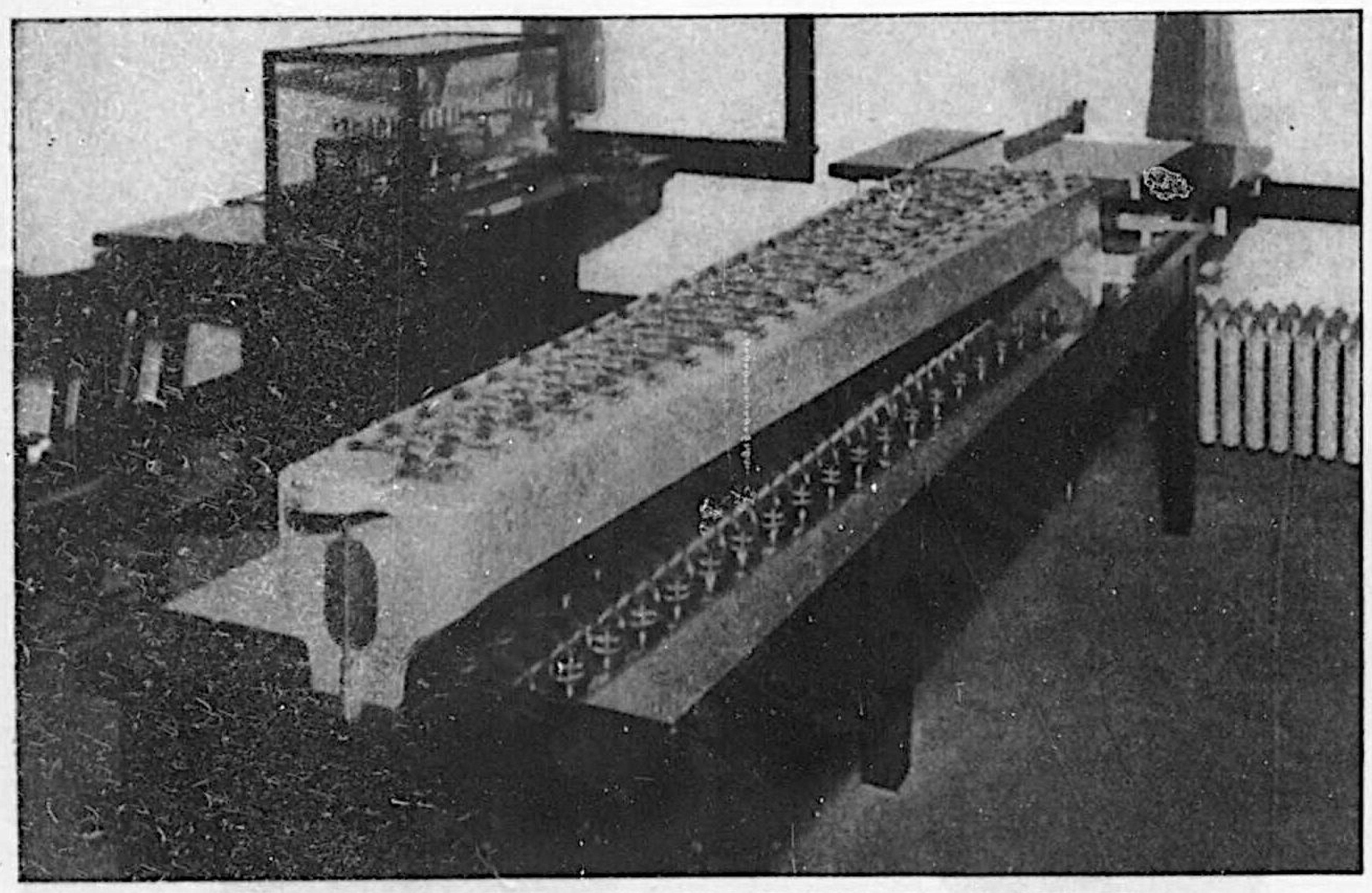
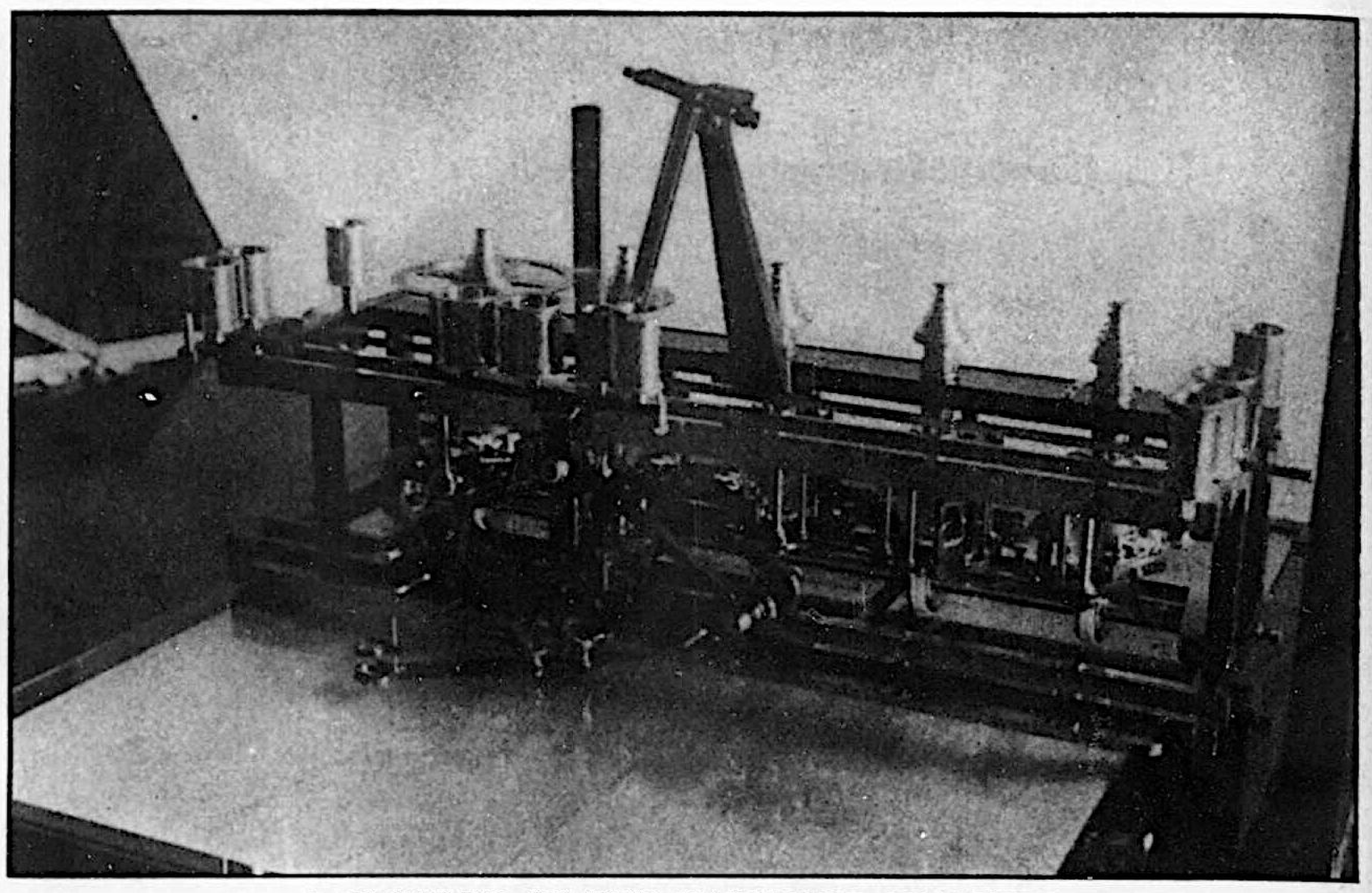


THE SYNTHESIZER AND THE HARMONIC ANALYZER

On the long table is the synthesizer which reconstructs sound curves from the readings that have been set up on the harmonic analyzer shown in the background



A CLOSE-UP OF THE HARMONIC ANALYZER

Seemingly made up of a maze of levers, wheels, belts, pulleys and glass balls, this intricate mechanism reduces sound curves to figures of the various components

Yardsticks of Sound

Sounds Are Now Reduced to Exact Mathematical Formulae and Reproduced at Will in the Acoustic Laboratory

By Austin C. Lescarboura

IMAGINE a steel fork worth several times its weight in gold! Plain steel, plain design, plain workmanship—at least so far as the most critical eye can detect. It is a two-pronged fork, with a short, stubby handle and thick, square prongs. Today this precious steel fork reposes in a silvery cabinet, with glass top and sides, and receives the respect accorded a rare relic. Occasionally it is carried by tender hands to a well-lighted hall where, surrounded by serious sages and forks of similar design, it is struck so that its penetrating wail may be heard far and wide.

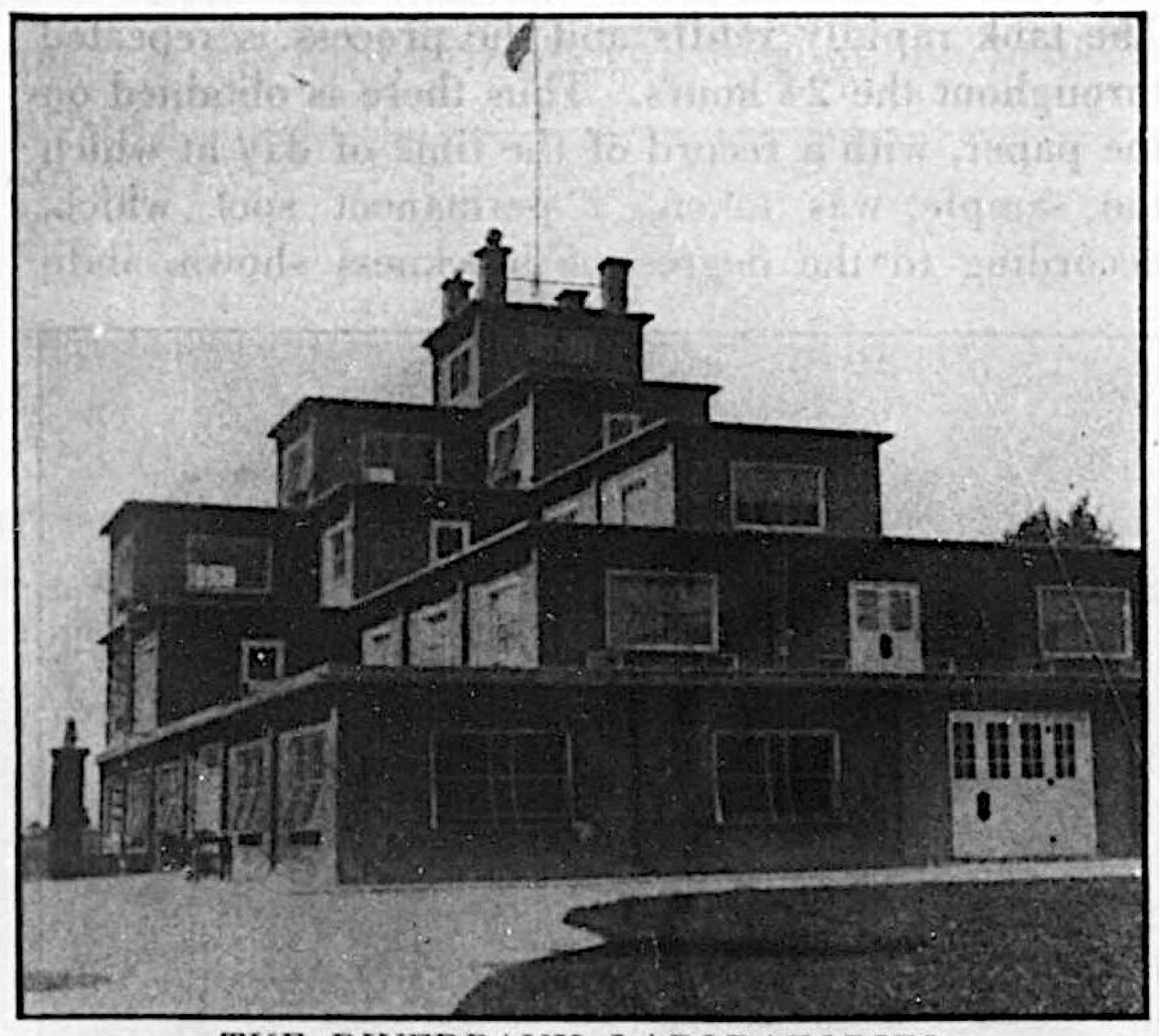
But enough of mystery! The fork in question is none other than the world's master tuning fork—at least it is claimed to be the most accurate tuning fork extant, by Colonel George Fabyan, in whose Riverbank Laboratories at Geneva, Illinois, this scientific marvel has been produced. This master fork, along with many other tuning forks in use or in the making in this institution, constitutes a standard of pitch, just as the platinum bar reposing in Paris constitutes the world's standard meter.

"Stirring Up" Solid Steel

The Riverbank master tuning fork, as with most tuning forks, fails to give even an inkling of the amount of skill and effort that went into its production. This steel form represents in its fashioning, tuning and polishing, at least 60 solid days of the most accurate craftsmanship and scientific procedure, while the total elapsed time was of the order of 18 months.

When used for a tuning fork, a mass of steel cannot be handled on the basis of "just so much metal." In their relation to accurate musical pitch, the molecules in the mass of steel for the fork-to-be act like so much mud in water which is stirred up every time the water is disturbed. Similarly, the molecules in the steel are easily "stirred up." Even with nothing more violent than the most gentle rubbing of the end of a prong with a bit of emery cloth, several hours are required for the "muddiness" or unsettled condition of the molecules of the metal mass to disappear, while the severe shock and upheaval of filing or other major machining, would persist for two weeks or more. Hence the considerable time required in the making of a precision tuning fork.

The pitch of a tuning fork is determined by the mass of metal in the prongs and down to the curved portion that leads to the handle. The handle itself plays no important rôle in the pitch, so that the clamping of the handle has no effect other than to alter the duration of the fork's sustained note. The



THE RIVERBANK LABORATORIES

One of the several buildings that constitute these laboratories where studies of sound and tuning forks, such as described in the text, are undertaken

vibrations of the fork can be transferred to other objects which will in turn vibrate to the same pitch, and with a volume depending on how much they are in sympathy with the pitch of the vibrating tuning fork.

In making a tuning fork of given pitch, the operation starts either with a drop forging or hand forging, roughly shaped to the approximate size and outlines of the ultimate fork, or with a solid block of metal which must be cut to shape and then carefully ground, rubbed and polished.

The master tuning fork at Riverbank is rated at "256 DV," which means that, when set in motion by a blow, its prongs will sway at the rate of 256 double vibrations per second, producing a note equivalent to the middle C of the musical scale of the physicist. Temperature, of course, influences the pitch, especially when dealing with such precise values. Rising temperature decreases the pitch, which is rated at 256 DV only when working at a temperature of 68 degrees, Fahrenheit (or 20 degrees, Centigrade). Correction factors permit of making due allowance for changes in temperature, so that the fork may be used accurately at any temperature.

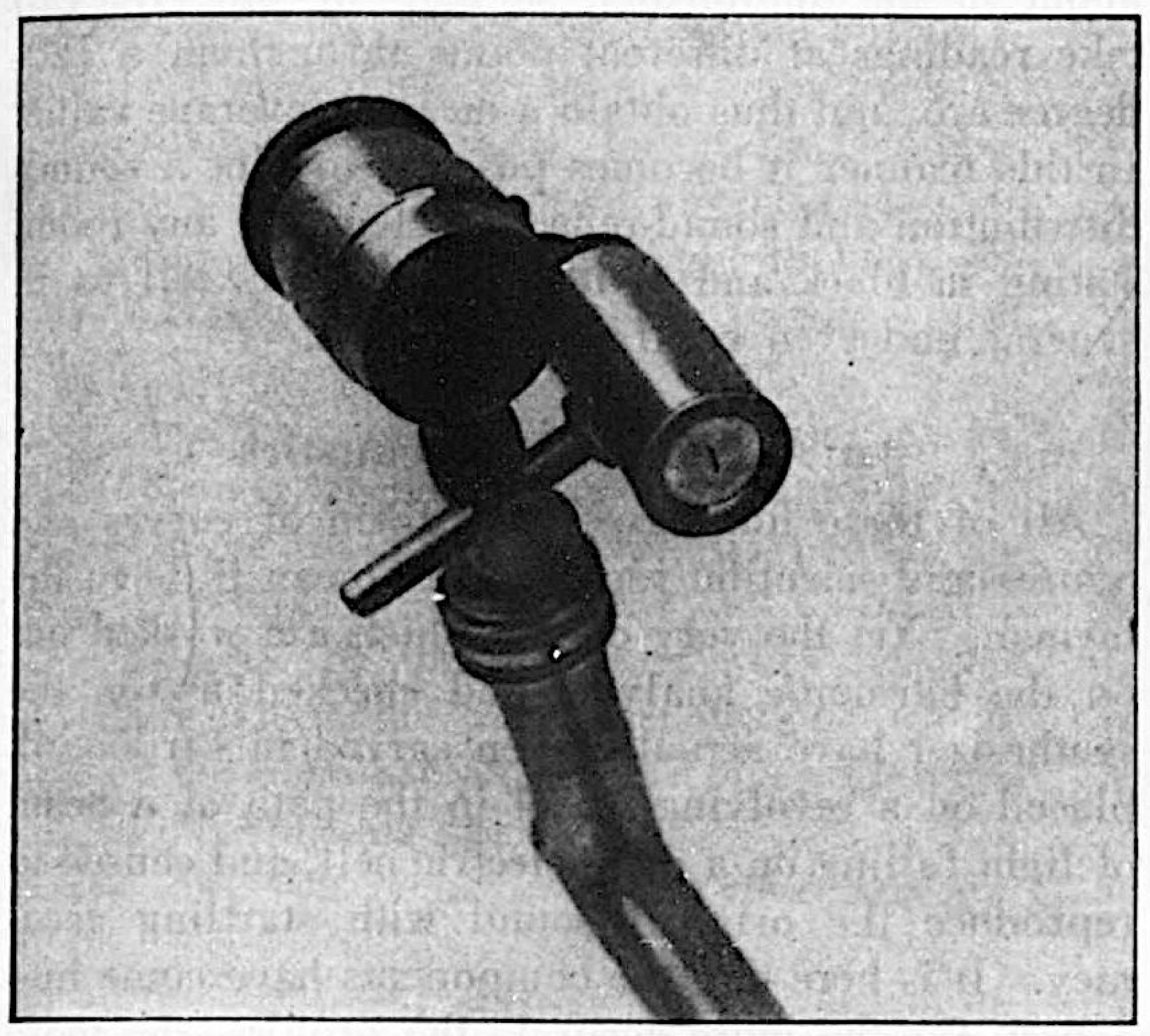
Few things are as delicate as a master tuning fork, despite its husky appearance. An invisible dent or tiny fleck of rust or corrosion on the prongs, due to careless handling or perspiring hands, would instantly change the pitch of the fork, even though only a fraction of a vibration per second. It would then no longer be a physical standard. The prongs are the most sensitive members, since they provide the elasticity which, in turn, determines the pitch. Even atmospheric conditions must be guarded against. To this end, the highly polished surface is coated at all times with light oil to prevent rust, and is carefully protected against mechanical injury.

141,000 Audible Vibrations

A master tuning fork is always struck with a soft, rubber hammer. However, to provide maximum protection, the Riverbank fork is enclosed in a metal case, with glass top and sides, and with a resonator chamber below, so that the sound may be plainly heard even though the source of the sound is fully protected. The master fork is set in vibration by a pair of arms which, when the knob outside the case is turned, spread the prongs of the fork apart and suddenly snap back, setting the fork vibrating. Thus the fork is protected from careless handling, and the actuating force is always uniform.

In order to gain the title of master tuning fork, extreme precision has had to be achieved. According to Bert Eisenhour of the Riverbank Laboratories staff, a classroom tuning fork is considered sufficiently accurate if it loses or gains one vibration in 750 of the indicated rating. The Riverbank master fork, on the other hand, loses or gains but one vibration in 500,000!

Quite aside from the matter of accuracy, there is the important requisite of sustained effort, or duration of the vibrations, especially in standardization work and advanced laboratory practice. It is the size or mass of the tuning fork, rather than its pitch, that determines its sustained effort, since it is possible to secure almost any pitch with any size of tuning fork, provided the metal is properly distributed. The Riverbank fork has a duration of nine minutes and 13 seconds, which, in terms of the vibrations themselves, means a total of 141,000 audible vibrations or more. This may be contrasted with a minute to two and one-half minutes for the best German tuning forks, or something like 15,000 to 34,000 vibrations.



EYEPIECE AND LAMP-HOUSE OF PHONOMETER
Note the narrow slit through which a light beam is flashed to the vibrating mirror situated within the device

Not content with such achievements, a new fork is now under way at this institution, using elinvar, a French alloy steel. This master fork will materially excel the performance of the present Riverbank standard. Its accuracy will be of the order of one part in a million and a half—one vibration gained or lost in 1,500,000—while the duration will be nine minutes and 56 seconds at 256 double vibrations per second, or something over 145,000 audible vibrations in all. Placing the master tuning fork in the metal case, with a resonator directly coupled, serves to intensify the sound, but this also reduces its period from over nine minutes to something like two minutes. However, for all practical purposes this period is sufficient, especially with the greatly increased volume due to the resonator.

It is in the final tuning of the master fork that the work is most precise and even tedious. Due to the "stirring up" of the molecules, only a tiny bit can be done at a time. The fork of known pitch and the fork being tuned are mounted at right angles to each other on a stout steel plate. A delicate wire, quite as fine as the finest hair, serves to couple the prong of one fork with the prong of another, and carries a shiny glass bead of almost microscopic dimensions. This bead rests in the field of vision of a powerful microscope. The work of tuning consists of removing just a trace of metal from the ends of the prongs at convenient intervals, with emery cloth, and then observing the results by means of the microscope and the oscillating glass bead. When the tuning forks are of equal pitch—which also means in perfect step—the glass bead will sway back and forth in a straight line, because of the uniform motion of the coupling wire, showing a straight streak of light in the microscope. When, however, the forks are of different pitch, or out of step, the glass bead does a scientific dance, resulting in a cycle of straight lines and curves from which, by means of a stop watch, the difference in vibration and therefore of pitch between the two forks, may be ascertained.

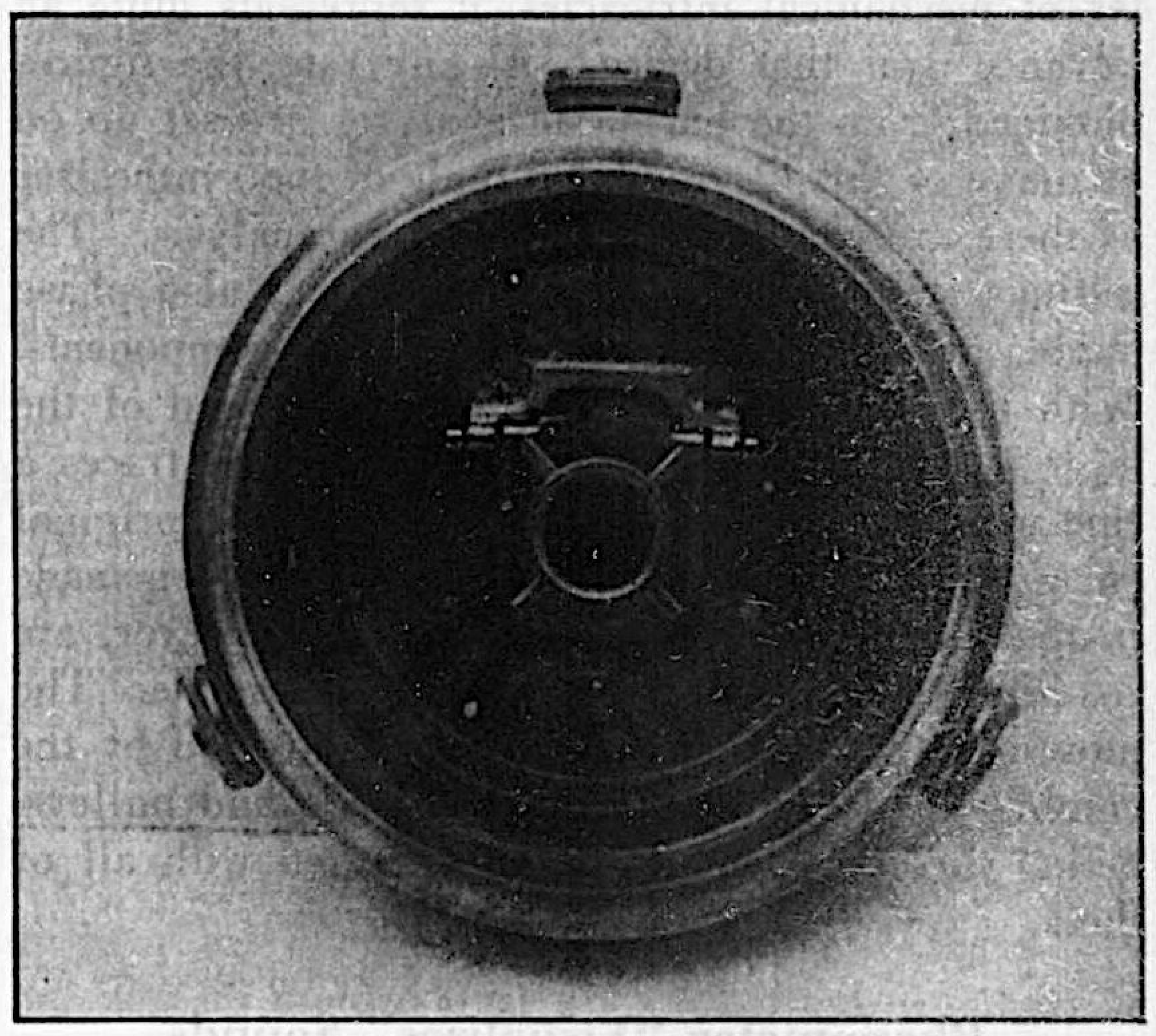
Handle With Care!

So, day after day and month after month, the maker of precision tuning forks fondly rubs the metal prongs with a bit of emery cloth, strikes both forks with a soft, rubber hammer, and studies the antics of the glass bead with stop watch in hand. Finally, after proceeding by infinitesimal shaving operations of one one-hundred thousandths of an inch, the forks are in step and the work is completed.

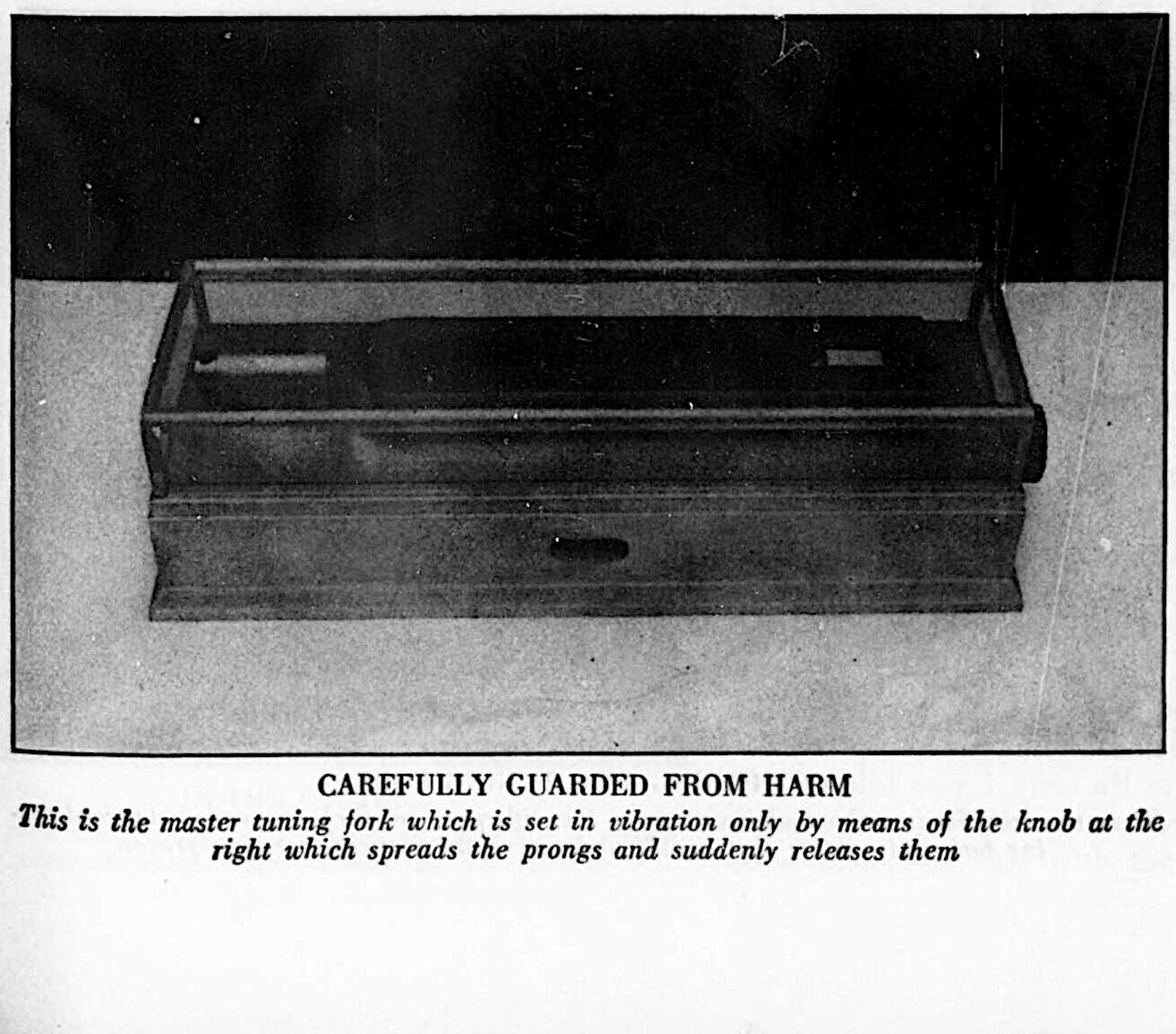
All kinds of tuning forks are to be seen at Riverbank, both in the finished form and in the making. Among others are those comprising a complete assortment from 512 DV to 4,096 DV, in steps of 128 vibrations. These tuning forks, as with others of equally high caste, are handled only with gloves and are struck only with prescribed soft, rubber hammers. When not in use, these forks are kept in a glass case and are covered with a thin coating of oil.

Tuning forks are the basis of a vast amount of scientific effort that must go into the study of sound. Now sound, as every schoolboy knows, is the result of vibration in objects and in air. Sounds are heard because vibrations, imparted to the air by vibrating objects, strike the human ear-drum which is set vibrating, and the vibrating ear-drum in turn communicates the effect to the brain where it is duly translated into certain sensations. Music, which we readily enjoy without stopping to think what it is all about, consists of a veritable riot of vibrations of all kinds and powers, producing the desired nerve stimuli in the listeners. Even the simplest musical note, such as a single note from the violin, consists of a combination of vibrations, with a predominant vibration to produce the fundamental pitch. It also has many subsidiary vibrations which produce the overtones and harmonics so essential for giving the timbre which characterizes a violin from other musical instruments, and even a Stradivarius from a mail-order special.

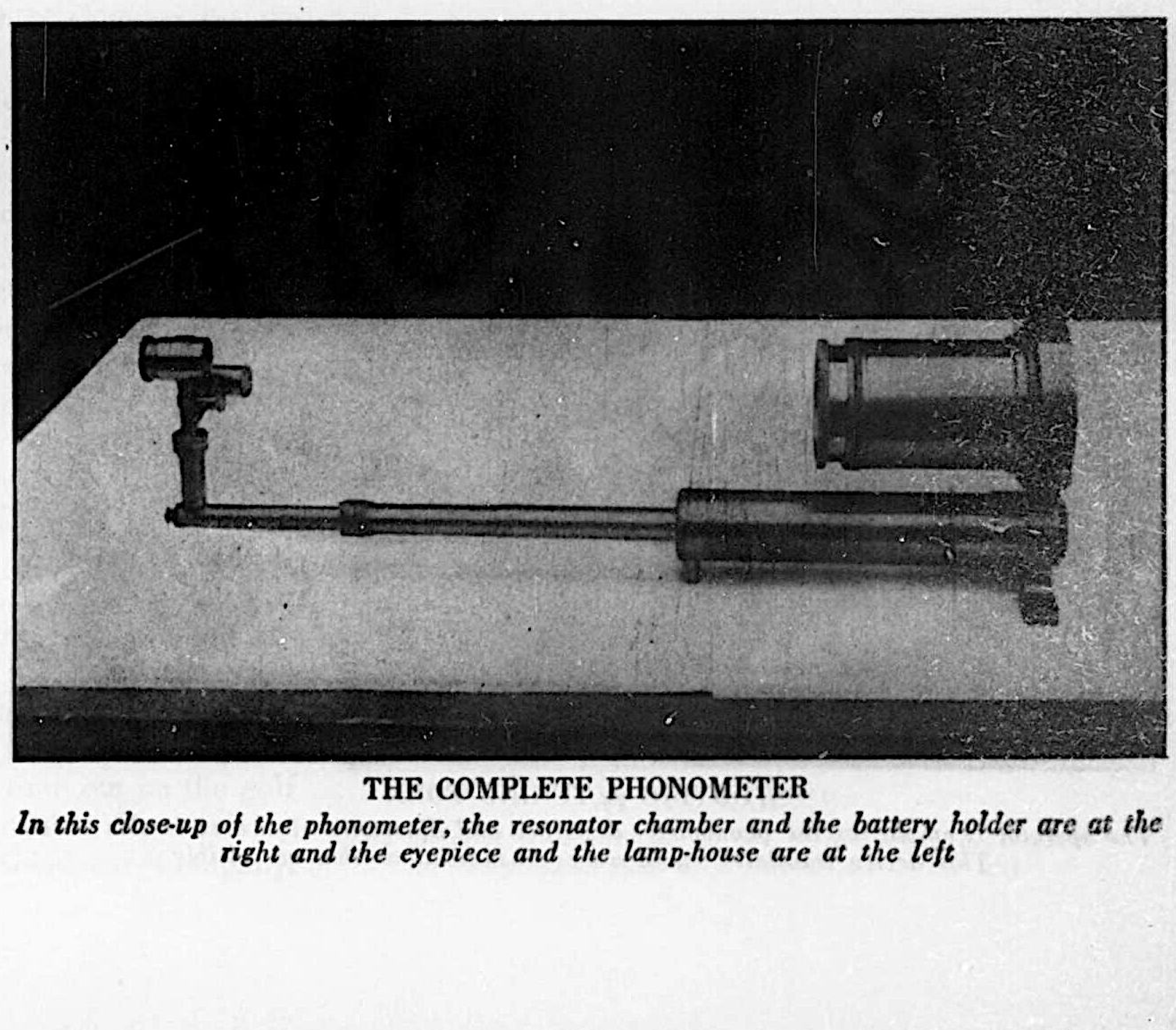
Among the many ingenious devices employed in the study of sound in the acoustic laboratory, is the harmonic analyzer—an intricate assembly of pulleys and cords, glass balls and celluloid scales, levers and hinges. A given sound is reduced to a graphic curve by means of other devices, such, for example, as the oscillograph camera. The graph is placed on the harmonic analyzer, and as the stylus of the analyzer is moved over the curve, the components that go to make up that particular curve and its particular sound are registered on recording dials, just as the ever-watchful electric meter keeps tabs on our consumption of electricity without encouragement on our part. Readings are obtained for the various components of the curve, even up to 40 components. We are told that, in determining the real constitution of the sound, readings up to ten components are quite crude and insufficient; 20 components is passable; 30 components is fair; 40 components is good; and 50 components means accurate analysis even for a fairly intricate wave-form such as that of a violin note.



THE HEART OF THE PHONOMETER
This shows the wires holding the disk which vibrates the mirror of the device, thus reflecting light to a scale



CAREFULLY GUARDED FROM HARM
This is the master tuning fork which is set in vibration only by means of the knob at the right which spreads the prongs and suddenly releases them



THE COMPLETE PHONOMETER
In this close-up of the phonometer, the resonator chamber and the battery holder are at the right and the eyepiece and the lamp-house are at the left

The intricate array of figures obtained with the harmonic analyzer must be checked over in order that the findings may be considered final. Heretofore, such checking up has called for mathematical ability of no mean order, plus a great deal of time. It has remained, however, for Mr. Eisenhour, of the Riverbank Laboratories staff, to develop a machine which does the checking up at the mere turning of a crank! The machine, which has been named the "synthesizer," comprises a vast array of wheels, pulleys, cranks, gears, and a transmission chain, tracing pen or pencil, crank and heavy base.

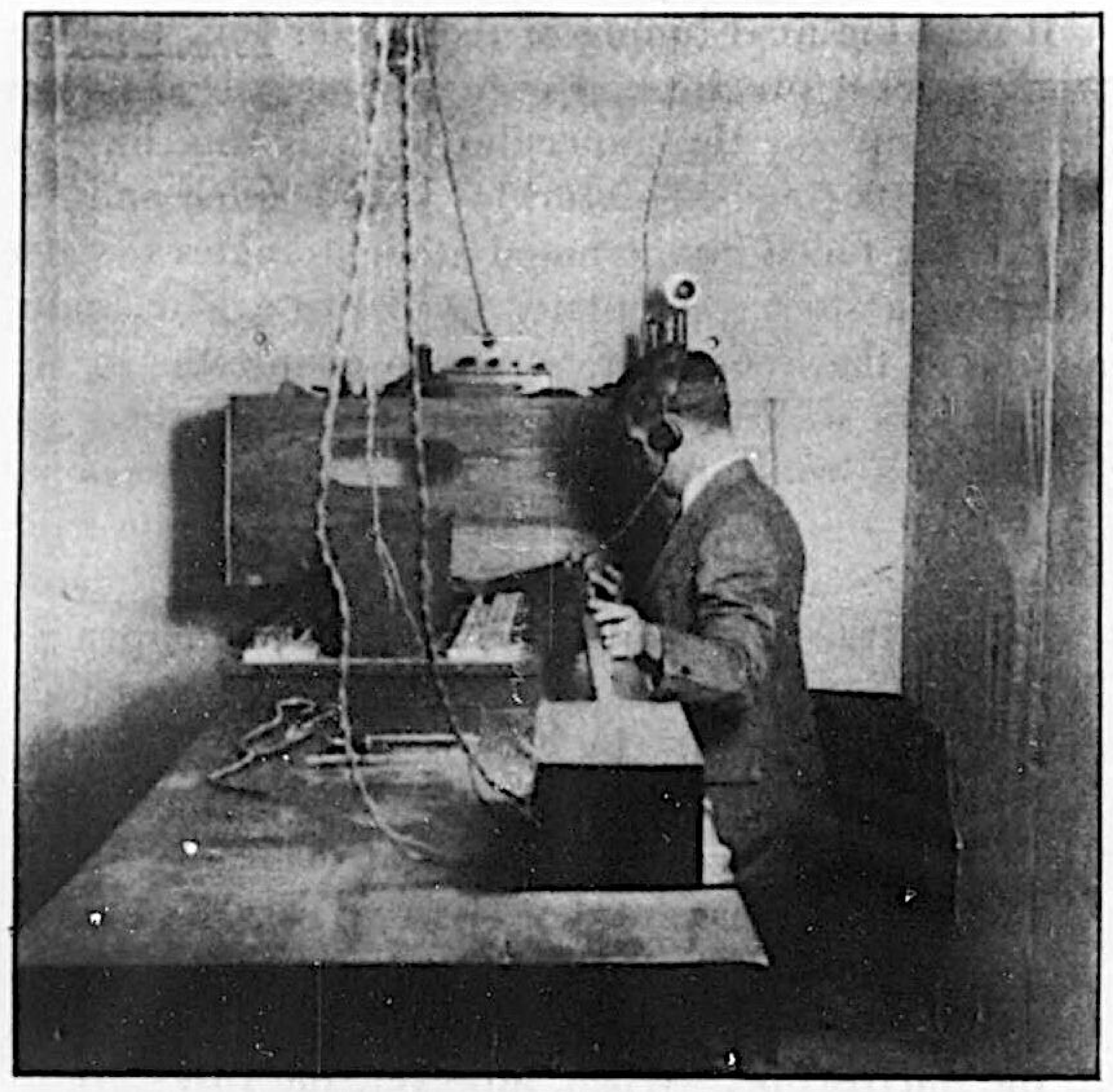
In a general way the synthesizer simulates the tide-predicting machine of Lord Kelvin, but, in the matter of mechanical intricacies, it represents quite an advance over that device. At any rate, the figures obtained from the harmonic analyzer are set up on as many of the 42 graduated dials of the synthesizer as there are components in the curve analysis. The settings stand for amplitude, or power; also phase angle, or difference in time between components. With the dials all set, the crank at the end of the table is turned, whereupon a pen or pencil traces a line which should coincide with that of the original curve analyzed, provided no errors have been made in the analysis and readings. Errors, however, are readily detected and due corrections are made. The movement of the pen or pencil is controlled by the combined action of all of the 42 dials and pulleys, acting through a chain drive connected with all of them.

Phonometer "Visualizes" Sounds

The synthesizer measures about nine and one-half feet long over all, with the main body tapering from two feet wide at one end to nine inches at the other. The main frame is of cast aluminum, the gears of steel, and the dials and other parts of stellite, a hard stainless composition which machines well and takes a high polish.

Not content with studying the science of sound amid laboratory surroundings, the staff at Riverbank have worked out ways and means of studying sound action in auditoriums, churches and halls, in order to determine the absorption and reflection of walls, as well as the cause of unsatisfactory acoustics. For this purpose an ingenious device, known as the "phonometer," has been developed. The original idea for this instrument came from the late Prof. A. G. Webster of Clark University. The present improved device has many advantages over the original model, both in scope and convenience, as well as in ruggedness.

The phonometer permits of "seeing" sounds even when they have become too weak to be heard by the



IN A PADDED CELL

Here the array of electrical devices shown permits the study of the effects of various sounds on the human ear

most sensitive of human ears. Furthermore, the phonometer gives a quantitative or volume reading, which cannot be expected of uncalibrated ears. Briefly, this instrument comprises a metal disk, suspended by three pairs of taut steel wires. This disk is set vibrating by the sound waves for which it is tuned. By altering the tension of the steel wires, the phonometer may be tuned to maximum response for musical frequencies ranging from 256 to 1,024 DV. The disk is enclosed in a resonating chamber, formed by sliding metal tubes and a plate-glass window, so that the air is attuned to the desired frequency and presents no drag on the vibrating disk. In its vibration, the phonometer disk, working through a tiny driving rod, causes a minute mirror to wobble. This mirror is just about large enough to permit a fly to study her complexion. Against the mirror is directed a tall and narrow beam of light from an electric lamp, and this beam, in turn, is reflected by the tiny mirror onto a graduated scale which is visible through a high-power magnifying eyepiece. Thus the vibration of the metal disk is translated into expanding and contracting ribbons of light on a graduated scale, suggesting nothing so much as an accordion in action.

The intensity of the sound results more or less in stretching of this figurative accordion, and the degree is read off on the phonometer scale. Just so long as a pushbutton is pressed, the beam of light is supplied by a miniature bulb encased in a lamp house beside the eyepiece. Current is obtained from flashlight cells in the tubular base of the phonometer. All in all, the device is entirely portable and self-contained, despite its extreme sensitivity which far exceeds that of the human ear.

It will be noted that the phonometer responds to the sound for which it is tuned, and that it ignores all other noises. Thus it may be used for testing the acoustics of a hall, even though carpenters and others may be at work. In working out sound distribution for auditoriums, a source of sound is employed, such as a calibrated organ pipe. A tuning fork would hardly supply sufficient volume for a large room and would have to be excited too often. The sound once liberated, the phonometer is carried about in the auditorium, so that the observer can take readings at different points throughout a 120-degree arc, and thus obtain a mean or average value. In this manner it becomes possible to plot a sound-distribution and sound-reflection chart for any room, stating in black and white what the ears tell us in general and even contradictory terms.

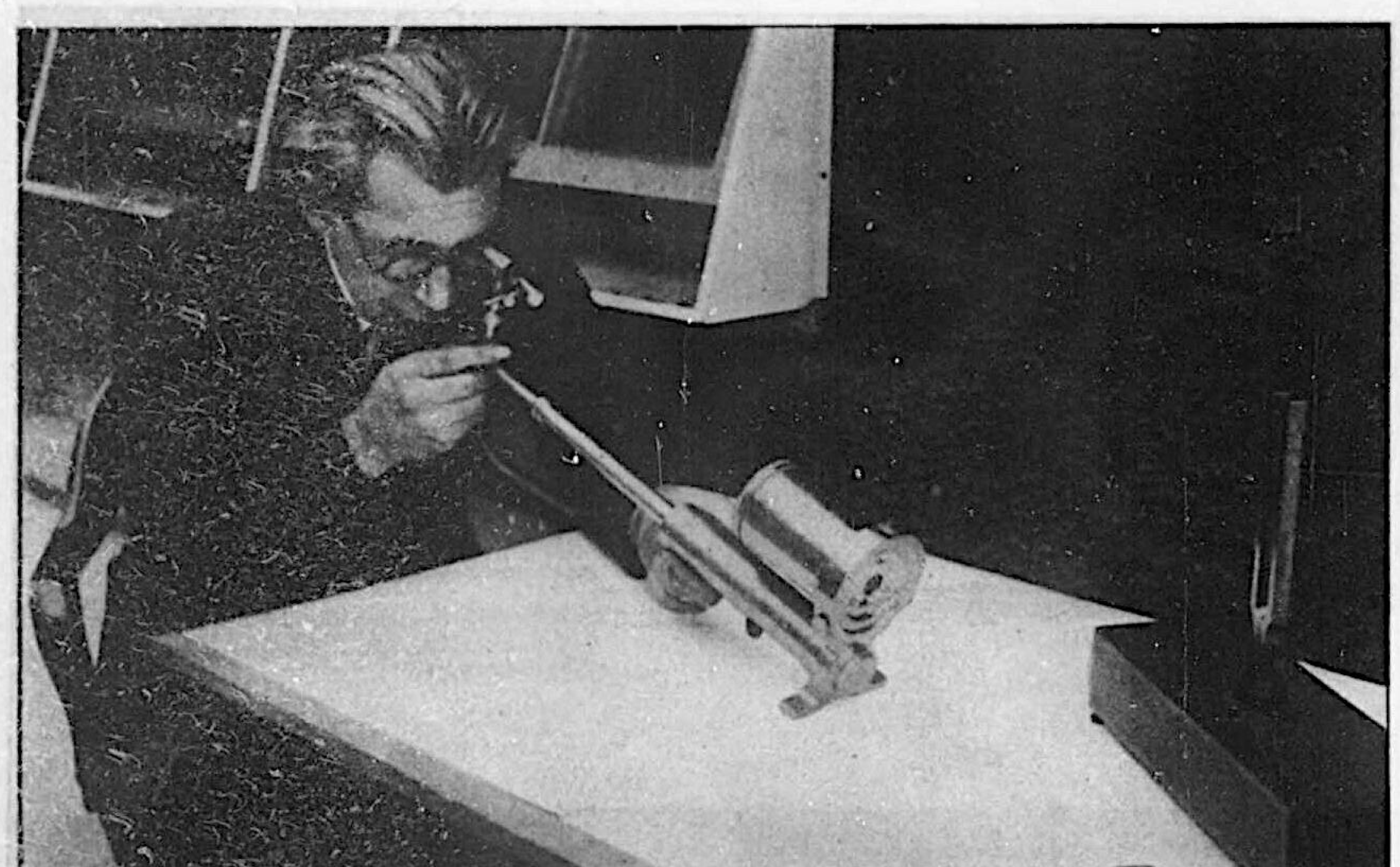
An Aid to Better Acoustics

All of these findings, in the form of curves and figures and scientific reports, may mean little to the layman. Yet the very curves which are worked out on the harmonic analyzer and checked up on the synthesizer have actually been carved in cardboard, placed on a revolving wheel in the path of a beam of light falling on a photoelectric cell, and caused to reproduce the original sound with startling accuracy. It is here that the components have come into action, for the more accurate the profile—the more little twists and turns are included, as the result of including more components—the more realistic is the reproduction.

The lessons learned in making observations on walls, draperies, furniture, architectural design and other things have served to produce better acoustic results in our homes, churches, auditoriums, theaters and even the broadcasting studios.

So in conclusion, we find that veritable yardsticks have been produced for the measurement of what has hitherto been one of the most elusive of nature's forces—sound. And with yardsticks in hand, the scientist can now advance to a better and still more practical understanding of sound, and to a vastly improved application of those intricate vibrations whose charms have been known to soothe the savage beast.

A new type of turbine-driven locomotive which holds many interesting advantages over those in existence at the present time will be the subject of a fully explanatory article that will appear in the June issue of this magazine.



STUDYING A TUNING FORK

The operator is employing the phonometer described and illustrated elsewhere in this article. This device translates sound waves to indications that are visible

COMPARING TWO TUNING FORKS

Here the scientist is making observations of the difference in pitch between a standard tuning fork and another that is still undergoing the intricate forming process