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A New Apparatus for the Enlargement of Phonograph Records

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Karl F. Muenzinger

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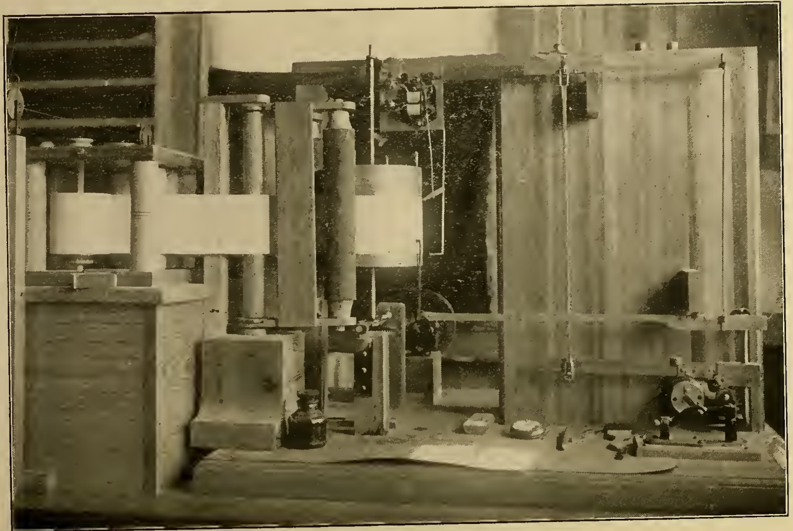

The Lever Arrangement
(Compare Fig. 1 of Plate I)

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The benefits of education and of useful knowledge, generally diffused through a community, are essential to the preservation of a free government.

Sam Houston.

Cultivated mind is the guardian genius of democracy. . . . It is the only dictator that freemen acknowledge and the only security that freemen desire.

Mirabeau B. Lamar.

PREFACE

Among the devices that have been put at the service of experimental phonetics, the phonograph and gramophone are especially noteworthy. Their records are relatively free from the psychological errors incumbent on most other devices; they have the widest range of application, registering simultaneously the acoustic effects of oral and nasal articulation, the different degrees of voice and sonority, strength and pitch of intonation, glides, quantity, etc. In addition to this, the relative indestructibility of newer records is an invaluable asset.

These advantages are generally admitted, and, still, experimental phonetics has thus far utilized the phonograph to a minor extent. The reason is obviously to be sought in the comparative invisibility of the phonograph curves—the *phonoglyphs*, as they are termed in this booklet. To magnify them in an accurate, but fairly convenient way has been recognized as a problem of great importance for some time. The instrument described in the following pages has solved it in a thoroughly satisfactory manner; in principle, it is complete in its present form; in details, especially as to certain automatic conveniences, it may easily be perfected as soon as time and funds will permit.

* * *

The construction of the apparatus was made possible by the far-seeing generosity of the authorities of the University of Texas, to whom we are desirous to express our gratitude and appreciation for making a special appropriation for this important instrument of research. The economic use of the funds thus granted is best characterized by the fact that the author of this booklet who had devised the apparatus, went so far as to do the major part of the manual labor himself. Thankful acknowledgment is due to Mr. L. H. Gruber, Mechanician of the School of Physics, without whose expert skill the author's efforts would have been in vain. The author is also indebted to his University colleagues for their readiness to help and willingness to advice; practically, however, no help was received from the outside.

* * *

Not only phoneticians, but psychologists and physicists as well, will clearly recognize the advantages of the new device. To me, however, being a philologist, its philological importance appeals first of all. Human ears are not sensitive enough to analyze the finer distinctions of human speech in their true values. We guess and grope in the dark and are dissatisfied with most of the present means of experimental investigation of speech sounds. The convenience of the apparatus described herein opens up a new, broad field of research, and it is my conviction that it ought to be given as wide a sphere of usefulness as possible.

I believe that this can be done most effectively in connection with a project of independent value. Scientific corporations in Europe are beginning to establish Phonogram Archives of the dialects existing within their immediate reach. The necessity for such a collection is even more pressing in the United States than in the case of European countries: Our dialects change more rapidly than those of Europe on account of the rapid variations in the ethnic character of our populations; certain Indian languages, negro speech and negro song of the south, are speedily disintegrating; the transitory progress of immigrants' English presents problems of language mixture of great linguistic and psychological weight. Facts bearing on such and many other problems must not only be preserved by means of a National American Phonogram Archive, but they must also be *studied* with its help, and, partly at least, through the medium of phonoglyph reproductions as described in these pages.

The first steps to establish such an archive, together with a reproducing bureau as an adjunct institution, have been taken. Their success will depend on co-operative enthusiasm.

E. Prokosch,

Professor of Germanic Languages in the University of Texas.

TALKING MACHINES

Of the various methods to obtain objective records of human speech, one has been developed very highly, namely, that of the "talking machine." As its name suggests, its purpose is primarily the reproduction of speech sounds. The principle common to all talking machines is this: A sharp point attached to a membrane which is caused to vibrate by sound waves, registers its oscillations on a soft surface, e. g., a rotating wax cylinder. This receiving surface is called the "record." Another point and membrane following the groove on this record, will reproduce sounds similar to those that caused the first membrane to vibrate. We should notice here that the wave line on the record (this line I shall call the *phonoglyph*) is by no means a picture of the sound waves, but represents only the movements of the center of the membrane, damped by the resistance of the wax. Again, the reproduction of sounds from a record does not contain all that is engraved on it, so that as to exactness the phonoglyphs may be said to stand between the original sounds and their reproduction. Accordingly, all that we hear is actually contained in the phonoglyph—an obvious, but important fact, as we shall see later.

Two kinds of talking machines are now made, the Phonograph and the Gramophone. Their general principle is explained above; the important difference between them is this: The writing point of the recording membrane of the phonograph cuts a wave lying in a plane which is at right angles to the plane of the receiving surface, while the writing point of the gramophone moves in a plane parallel to that of the receiving surface. A minor difference consists in the use of revolving discs as records by the gramophone, and of rotating cylinders by the phonograph. The latest model of the phonograph, however, also uses discs.

METHODS OF TRANSCRIBING AND ENLARGING PHONOGLYPHS

The phonoglyph is extremely small. This fact makes its study with the naked eye impossible; even with the aid of a microscope it is still a difficult task. An enlarged reproduction of the phonoglyph seems therefore to be indispensable to accurate study. Various kinds of apparatus for enlarging have been devised. It is not my intention to describe them all, but only to mention the typical constructions.

Air transmission. McKendrick (Nature, 1909, April) joined the sound box of one gramophone to that of another. The first one played the record in the usual way; the second registered its vibrations on smoked glass. W. E. Peters (Vox, 1913, 261) changed this method by replacing the second sound box with a tambour similar to the Laryngograph of Krueger-Wirth. The advantages of this method are as follows: It is inexpensive; it does not require much skill to handle the apparatus; the speed of reproduction is as fast as is desirable. (It takes as long to transcribe a record as to play it.) The disadvantages are two: First, the difficulty of reading the phonoglyphs is still very great, since they are only slightly magnified in the process; second, their correctness is very doubtful, since the errors of the sound box are greatly multiplied in the threefold transfer, that is, in being recorded, reproduced, and recorded again.

Electric transmission. McKendrick and Peters also produced an apparatus in which a gramophone sound box was joined to a microphone. An electromagnet to whose armature a stylus was attached, was used as "receiver." While the advantages of this method are about the same as those of the one mentioned above, its disadvantages are greater, since the inaccuracies of the electric transmission and of the movement of the armature are added to those of three vibrating membranes.

Stiff levers. Enlargement by stiff levers seems to be the most simple and direct method. Moreover, by using a combination of several levers, connected with each other, one may magnify to almost any degree desired.

E. W. Scripture (Researches in Experimental Phonetics, Washington, 1906) has built an apparatus on this principle for the enlargement of gramophone records. He used very light and rigid material for his levers, and jewel bearings. The long arm of the first lever is connected with the short arm of the second by a stiff rod between gimbal joints. A glass point at the end of the long arm of the second lever writes on smoked paper. To the short arm of the first lever is attached the needle which runs in the groove on the disc. The exactness of the apparatus must be very great. Judging from the results which E. W. Scripture obtained, I would say its only two drawbacks (so far as I can see) are the difficulty of its construction, and its low speed, one revolution of the gramophone disc taking about four hours. Scripture also constructed an apparatus for the enlargement of phonograph records. This instrument has but one lever. Two and three levers are used by the instrument-maker H. Lioret, of Paris. This so-called "Lioretgraphe" is now employed in several laboratories; I shall describe its more important points below.

Optical lever. The principle of enlarging with an optical lever is as follows. A small one-arm lever carrying a mirror, follows with its free end the groove on a record. Its movements may reflect a ray of light, which, if photographed, represents an enlargement of the phonoglyph. Lioret has constructed on this principle an apparatus for enlarging phonograph records. However, the specimens of curves obtained with it, and reproduced in his catalogue, do not appear to be very satisfactory. Hermann, one of the first investigators in this field, used a combination of two (and later three) levers, fixing the mirror on the last one. His method thus is a combination of the stiff lever and the optical lever methods. His results seem to be very satisfactory (Pfluegers Archiv, vols. XLV., XLVII, LIII, and others.) A remarkable point of construction will be mentioned below.

DESCRIPTION OF APPARATUS

The apparatus which I constructed for the enlargement of phonograph records is of the type which has a combination of stiff levers. I chose the phonograph, instead of the gramophone records for the practical reason that the making of new phonograph records is a comparatively simple process; so that for certain experimental purposes I am not dependent on the commercial records, but can use those that contain linguistic material prepared by myself. In describing the apparatus I shall first take up the levers, and then the movements of the cylinder and of the writing drum.

The lever system. The lever arrangement is shown in the photograph and fig. 1 at the end of this paper. Lever I, with the pivot *a*, holds the glass point or sapphire *b*, which follows the phonoglyph on the record. At point *c*, a rod A joints with lever I, connecting it with lever II at point *d*. The point *e* is the pivot of lever II, whose longer arm at *f* is connected by rod B with the shorter arm of lever III at *g*. This lever, with pivot *t*, bears at the end of its longer arm the hinge *i*, with the writing arm W, leaning against the paper.

The principle of this lever is simple, and does not contain anything original, except the position of the writing arm. Of more importance, however, are the details of construction, which, so far as I am able to judge, give this apparatus a superiority over others built according to the same principle.

The three probable sources of errors in a lever system are the bearings, the lever connections, and the material. Special attention has been paid to these points, as will be shown in the following paragraphs.

The pivots. The crucial point of a lever is its fulcrum. It must possess a true axis, and as little friction as possible. Jewel bearings, like those used in a watch, will serve the purpose well. At first I provided each lever with such a bearing (*a*, *h*, *e*). But I discovered that the adjustment was not easy. By turning the adjusting screw, a point where the friction was least had to be found, and at the same time, the center of the axis and the centers of the jewels were preserved in one straight line. Later I replaced *h*, and *e*, with modified V-bearings (fig. 2) with this arrangement. No adjustment is necessary; there is always the same accuracy of adjustment and almost no friction. To reduce the possible errors of the bearings I decided to use long levers. It is plain that the movement about the fulcrum is lessened as the arms of the lever are made longer. Lever I must be the most accurate and dependable. I therefore made the small arm *ab* 40 mm. long.

Points of application. Another requirement of a good lever of this kind is that its fulcrum and the ends of its arms be in one straight line. Moreover, these connecting lines (fig. 1) *abc*, *def*, and *ghi*, ought to be parallel to each other when in a neutral position, and the rods A and B ought then to be at right angles to them. Take, for instance, the ends *d*, and *f* of lever II (fig. 3). They move in two concentric circles around the pivot *e*, whereas they ought to move in the direction of the perpendiculars to *df*, in *d* and *f;* in that case the arcs in the immediate neighborhood of *d* and *f* may be said to fall together with the perpendiculars.

A condition of greater importance is that the line *ab* be a tangent to the cylinder. Only in this case an exact reproduction of the phonoglyphs may be expected. This precaution is not observed in the Lioretgraphe, where *ab* lies in a line which cuts the cylinder in two points. The result is that the reproduction (which I shall hereafter call the phonocurve) will be distorted.

Shifting the record. Every apparatus with which I am acquainted contains some device for shifting the record or the sapphire *b*, so that the latter may follow the spiral groove on the record. Such a device is not at all necessary. On the contrary, it makes the manipulations of the apparatus more difficult. Oftentimes it is desirable to repeat the reproduction of a number of revolutions several times before going farther. In that case it would be necessary to turn the instrument back until the sapphire reaches the point desired. To avoid this inconvenience, and to simplify construction, the following way has been pursued. The tapered drum bearing the record is not fixed on its shaft, but may be shifted back and forth by hand. It also has a key fitting into a key-way in the shaft, so that it can be turned by the shaft. In order to allow the sapphire on the record to be moved in the direction of the shaft, the base of bearing *a* is not fixed, but is connected with another bearing whose axis is at right angles to that of *a* (fig. 4). By turning the record, the sapphire will be shifted to one side. Up to 10 revolutions there is no noticeable error due to this side movement. The drums may be shifted then along its shaft, until the sapphire is again in its former position. Or, if the reproduction of the ten revolutions is to be repeated, the sapphire is placed back. In either case, the axis of the movement is *a′*. Since the distance between *a′* and *b* is rather large, 80 mm., the short path traveled by the sapphire falls practically together with a parallel to the axis of the drum, provided the lever in its neutral position is at right angles with the axis. The result is finally the same as if the drum (or the sapphire) had been shifted by a worm screw.

The side movement of the sapphire will be magnified at the end *c* of lever I. Theoretically, this will change the distance between this point and the end *d* of lever II. However, if the connecting rod *cd* is taken sufficiently long—in our case it is 450 mm.—no error can be detected coming from this source.

Lever connection. After many experiments and failures, the problem of connecting the levers was solved in the following way, which is most simple and practical. The levers are balanced so that the ends to be connected pull in opposite directions, i. e., *c* and *d* pull away from each other, and *f* and *g* towards each other. By this arrangement they can support the connecting pieces between themselves. Rod A is suspended between *c* and *d* as shown in fig. 5. The cone which represents the end *d* of lever II is of hard steel, like the conical bearing into which it fits. This bearing is held by an aluminum frame at the end of rod A. The arrangement at *c* is similar. Rod B holds the conical bearings directly at its ends as shown in fig. 6. The advantages are that there is almost no friction, so that great accuracy is obtained, since one joint has but one bearing point. Scripture uses gimbal joints, in which one joint has four bearing points.

Hermann has a unique way of connecting his levers, that does not appear to be very exact. A glass rod fastened to one lever passes against a glass plate on the other. A serious cause of inaccuracy is the fact that the end of the glass rod does not move in the direction of a perpendicular to the lever, but in a circle with the center at the fulcrum of the lever. The shortness of the levers makes the error from this source rather pronounced.

Lioret uses a fork at the end of the long arm of one lever, which acts on a pin on the short arm of the other. Quite a little friction is created this way, not to mention the danger of lost motion.

Material. The material of the levers must be non-bending and as light as possible. I have used poplar with good result. All parts of the lever system, with the exception of lever I, were made just heavy enough to insure the necessary stiffness, since very much depends on the weight of the whole system. When in motion, the system acquires a certain momentum, which may result in a motion of its own. To avoid this, the speed of the instrument has to be adjusted according to the weight of the system. It was found that with an enlargement of 1:300 the record may safely turn once in 10 minutes. (The record of Scripture's apparatus turns once in 4½ hours.)

The stylus. The end *i* of lever III carries the stylus W, which also differs materially from that of other instruments. If the stylus were attached directly to the lever, it would move in a circle with the center at its fulcrum *h*. The tracings would then contain a distortion, which would have to be taken into account. To preclude the necessity of this complicated correction, another arm W, was connected by a fine watch bearing (later by a paper hinge) with lever III at *i*. This arm W, which is almost perpendicular to the lever, carries at its end a gold writing pen such as that used in a recording barometer. It leans against the writing drum with a very slight pressure; therefore the friction of the pen writing on smooth paper is very small. Now, the circular movement of the end *i* of lever III has no influence on the curve. Theoretically, an error appears, because *i* does not move parallel to the paper; but this error does not show in the tracing if the arm W is made sufficiently long. For the purpose of comparison, smoked paper has been used on the drum, and a pointed piece of straw for a stylus (instead of the smooth paper and the gold pen). It was found that there was no practical difference. Although the point of the pen is a cause of annoyance and requires much care if the line which it is drawing is to be thin, there is much less labor than in the case of smoked paper, considering also the fact that one record yields a curve about a mile long.

Balancing the levers. The relative weights of the several lever arms is as follows: Lever I presses down at *c*, II at *f*, and III at *i*. By the help of a moveable weight attached to the smaller arm of III, the balance of the system is adjusted. If disconnected at the end *c* of the first lever, the remainder must be able by its own weight, and that of the adjustable weight on

III, easily to overcome the friction of the pen moving upwards. After the system is joined again at *c*, the weight of lever I ought to overcome the friction of the pen moving downwards. In addition to this it must be heavy enough to keep the sapphire *b*, with a gentle pressure always in the groove of the record. A small weight which can be shifted along on I, helps to adjust this pressure.

Magnification. The cones at *c* and *d* may be moved toward, and away from, the pivots *a* and *e*, so that almost any magnification of the breadth of the phonoglyphs may be obtained. With jewel bearings at *h* and *e*, magnifications up to 300 were quite correct, and the handling of the instrument was comparatively easy. Beyond this, however, no satisfactory results have been obtained thus far. This is due probably to the friction and imperfect adjustment of the bearings. With V-bearings at those points, larger and more correct magnifications are obtainable. Up to this time, not enough trials have been made to speak with certainty of an upper limit. For most purposes, however, an enlargement of 1 : 300 is quite sufficient.

Magnification of the length of the phonoglyphs is obtained by moving the surface of the writing drum faster than that of the record. By properly conecting them the tracing can be stretched out as long as desired. I have used mostly an enlargement of about 1 : 5. Since the movement of both, drum and record, is rather slow, I decided to join them directly with speed reducers, which consist of a set of cogwheels. Belts would be rather unreliable at such a point. They are used only to connect the speed reducers with each other and with the motor.

Horizontal and vertical enlargement have to be in a certain definite relation to each other in order to make a good curve. (See plate II, A.)

As the drum moves, a strip of writing paper, pressed against it by rubber rolls, is also moved along. Near the drum is a mechanical arrangement for unwinding the paper roll and winding it up. (Fig. 7.)

Revolution marker. In order to know exactly what length of paper represents one revolution of the record, I fixed four contact points, 90° distant from each other, on the shaft which turns the record. As they touch a brass strip, an electric circuit is closed which contains a time marker at the drum. Thus every quarter revolution of the record is marked off on the paper. The distance from one mark to the fourth mark following measures one complete revolution. The whole of the paper is marked in this way in order to check the exactness of the enlargement as to the length, and to facilitate the analysis of the phonocurves.

To avoid all trembling and jarring, the motor is placed on a table by itself, while the instrument does not stand on the floor of the room, but on four concrete blocks reaching to the ground.

ANALYSIS OF THE PHONOCURVES

A phonocurve contains the greatest part, if not all, of the phonoglyphs. We may therefore expect at least a representation of what we hear when the record is reproduced in the usual way. Indeed, while analysing a phonocurve, we must continually compare it with the reproduction of the record itself. Only thus can we avoid unwarranted speculations as to what the phonocurve means. This is one of the greatest advantages of this method of studying speech sounds. In analyzing a tracing of Krueger's Larnygograph, for instance, we must largely rely on our memory for determining its contents.

The first thing to do in studying a phonocurve, is to distinguish and to mark off, pieces of it, as representing certain sounds. This is not at all easy. While listening to the reproduction of the record we count its revolutions. At convenient places, especially where large pauses occur, we make a copy of the text and write down the number of revolutions thus far counted. Since the phonocurve is already divided by the time marker as described above, the strips representing certain sentences can then be found. In a similar way parts of the sentences are determined, and finally the beginnings and ends of the words. This procedure has to be repeated many times before we can tell exactly what part of the curve corresponds to a particular word.

With the help of the phonetic script we try to represent the sound composition of words. The phonocurve is nothing but such a phonetic transcription with unfamiliar symbols or letters. It has a high degree of exactness in some respects, and serious shortcomings in others. Certain consonants, the voiceless stops, cannot be seen directly at all, while others can be recognized only with difficulty. But the liquids and nasals, and especially all vowels, do appear very plainly. It is here that no phonetic script equals the phonocurve. Not the sounds are represented, but the sound waves, so that we get the composition of the individual sounds, as they change from wave to wave. Very seldom do we find a clear division between consecutive voiced sounds; moreover, the form of a wave of a certain sound frequently is transformed gradually into the characteristic wave form of the following sound. (See plate II, B.)

This makes the above-mentioned marking-off difficult, when a word ends in a voiced sound, and the next word begins with one. Coming to the next step, the distinguishing of the sounds in a word, we are confronted with this difficulty even more frequently. One practical way to solve it is to follow up one wave form in one direction, and another form in the opposite (approaching) direction, until we find a neutral point that can be claimed with probability by both sides.

This determining of words and sounds is the elementary step of the analysis, and is indispensable to all further work.

Qualitative analysis. Qualitative analysis of phonocurves is the richest field of investigation that is offered to the student of phonetics. The ear is not sensitive enough to give an account of certain facts of pronounciation that, nevertheless, can easily be noticed in the "objective" record of a gramophone disc or phonograph cylinder. E. W. Scripture has some interesting specimens of such analysis (Researches in Exp. Phon., 39 ff), but nothing on a larger scale has been done so far.

Quantitative analysis. Much work has been done in the quantitative analysis of the phonocurves. The study of the speech melody has been the favorite subject in this direction. (Cf. Peters, Vox., 1914, 180.) The harmonic analysis of particular waves has also been studied by many, especially by Hermann. (Pfluegers Archiv, XLV, XLVII, LIII.)

REMARKS ON THE TRACINGS ON PLATES II AND III

All tracings are to be read from right to left. Only those in II, B and C are continuous, that is, the left end of one line must be regarded as continuing with the right end of the next line.

In the horizontal direction 1mm of the paper represents .000375seconds, except that part occupied by the fourth and second tracing in A on plate II, where 1mm=.00093sec.

The peculiar bending of the tracings is due to the fact that the surface of the record is not a perfectly true cylinder.

The five tracings under A on plate II represent five different enlargements of the same phonoglyph. The first, third and fifth have the horizontal linear enlargement 1 : 5. The vertical enlargement has been changed in the third and the fifth by shifting the connection *d* on lever II closer to its fulcrum *e*. The change in the horizontal enlargement of the second and fourth were made by using a smaller pulley at the speed reducer connected with the record.

Unfortunately the technique of reproduction did not do justice to all of the tracings. This is particularly noticeable in the phonocurves of the "i" on plate II, C and on plate III.