UNIVERSITY OF CALIFORNIA PUBLICATIONS
IN
AMERICAN ARCHAEOLOGY AND ETHNOLOGY

Vol. 12, No. 5, pp. 195-218, plates 1-5 October 11, 1916

# ON PLOTTING THE INFLECTIONS OF THE VOICE

BY

CORNELIUS B. BRADLEY

UNIVERSITY OF CALIFORNIA PRESS
BERKELEY

UNIVERSITY OF CALIFORNIA PUBLICATIONS

DEPARTMENT OF ANTHROPOLOGY

The following publications dealing with archaeological and ethnological subjects issued under the direction of the Department of Anthropology are sent in exchange for the publications of anthropological departments and museums, and for journals devoted to general anthropology or to archaeology and ethnology. They are for sale at the prices stated. Exchanges should be directed to The Exchange Department, University Library, Berkeley, California, U. S. A. All orders and remittances should be addressed to the University of California Press.

European agent for the series in American Archaeology and Ethnology, Classical Philology, Education, Modern Philology, Philosophy, and Semitic Philology, Otto Harrassowitz, Leipzig. For the series in Botany, Geology, Pathology, Physiology, Zoology and also American Archaeology and Ethnology, R. Friedlaender & Sohn, Berlin.

AMERICAN ARCHAEOLOGY AND ETHNOLOGY.—A. L. Kroeber, Editor. Prices, Volume 1, $4.25; Volumes 2 to 10, inclusive, $3.50 each; Volume 11 and following, $5.00 each.

Cited as Univ. Calif. Publ. Am. Arch. Ethn. Price

Vol. 1. 1. Life and Culture of the Hupa, by Pliny Earle Goddard. Pp. 1-88; plates 1-30. September, 1903 ........ $1.25

2. Hupa Texts, by Pliny Earle Goddard. Pp. 89-368. March, 1904 ........ 3.00

Index, pp. 369-378.

Vol. 2. 1. The Exploration of the Potter Creek Cave, by William J. Sinclair. Pp. 1-27; plates 1-14. April, 1904 ........ .40

2. The Languages of the Coast of California South of San Francisco, by A. L. Kroeber. Pp. 29-80, with a map. June, 1904 ........ .60

3. Types of Indian Culture in California, by A. L. Kroeber. Pp. 81-103. June, 1904 ........ .25

4. Basket Designs of the Indians of Northwestern California, by A. L. Kroeber. Pp. 105-164; plates 15-21. January, 1905 ........ .75

5. The Yokuts Language of South Central California, by A. L. Kroeber. Pp. 165-377. January, 1907 ........ 2.25

Index, pp. 379-392.

Vol. 3. The Morphology of the Hupa Language, by Pliny Earle Goddard. 344 pp. June, 1905 ........ 3.50

Vol. 4. 1. The Earliest Historical Relations between Mexico and Japan, from original documents preserved in Spain and Japan, by Zelia Nuttall. Pp. 1-47. April, 1906 ........ .50

2. Contribution to the Physical Anthropology of California, based on collections in the Department of Anthropology of the University of California, and in the U. S. National Museum, by Ales Hrdlicka. Pp. 49-64, with 5 tables; plates 1-10, and map. June, 1906 ........ .75

3. The Shoshonean Dialects of California, by A. L. Kroeber. Pp. 65-166. February, 1907 ........ 1.50

4. Indian Myths from South Central California, by A. L. Kroeber. Pp. 167-250. May, 1907 ........ .75

5. The Washo Language of East Central California and Nevada, by A. L. Kroeber. Pp. 251-318. September, 1907 ........ .75

6. The Religion of the Indians of California, by A. L. Kroeber. Pp. 319-356. September, 1907 ........ .50

Index, pp. 357-374.

Vol. 5. 1. The Phonology of the Hupa Language; Part I, The Individual Sounds, by Pliny Earle Goddard. Pp. 1-20, plates 1-8. March, 1907 ........ .35

2. Navaho Myths, Prayers and Songs, with Texts and Translations, by Washington Matthews, edited by Pliny Earle Goddard. Pp. 21-63. September, 1907 ........ .75

3. Kato Texts, by Pliny Earle Goddard. Pp. 65-238, plate 9. December, 1909 ........ 2.50

4. The Material Culture of the Klamath Lake and Modoc Indians of Northeastern California and Southern Oregon, by S. A. Barrett. Pp. 239-292, plates 10-25. June, 1910 ........ .75

5. The Chimariko Indians and Language, by Roland B. Dixon. Pp. 293-380. August, 1910 ........ 1.00

Index, pp. 381-384.

Vol. 6. 1. The Ethno-Geography of the Pomo and Neighboring Indians, by Samuel Alfred Barrett. Pp. 1-332, maps 1-2. February, 1908 ........ 3.25

2. The Geography and Dialects of the Miwok Indians, by Samuel Alfred Barrett. Pp. 333-368, map 3.

3. On the Evidence of the Occupation of Certain Regions by the Miwok Indians, by A. L. Kroeber. Pp. 369-380. Nos. 2 and 3 in one cover. February, 1908 ........ .50

Index, pp. 381-400.

UNIVERSITY OF CALIFORNIA PUBLICATIONS
IN
AMERICAN ARCHAEOLOGY AND ETHNOLOGY

Vol. 12, No. 5, pp. 195-218, plates 1-5 October 11, 1916

# ON PLOTTING THE INFLECTIONS OF THE VOICE

BY

CORNELIUS B. BRADLEY

## PREFATORY NOTE

When first undertaken, the study which forms the subject of this paper was no more than a mere incident in the attempt to clear up the confusion and uncertainty which till then had beset a certain question of phonetics, namely, the precise nature of the tonal inflections or modulations which, in languages of the Chinese type, are essential features of every spoken word. The conclusions reached through scientific analysis and measurement of wave-lengths could not be made convincing and conclusive without the help of a thoroughly accurate and trustworthy scheme for representing them visually. The time and the effort actually spent in perfecting such a scheme, which is, of course, a mere instrument, may seem altogether disproportionate to the end in view. But the perfect instrument was in this case absolutely necessary to the attainment of the end; and a scientific quest is not to be lightly abandoned because the tools for it are not ready to hand.

The scheme finally worked out is one which enables the student to translate accurately to the eye the physical facts which the ear reads as figure or movement within the field of pitch. It was shaped for a definite and single use. But a perfected instrument often finds much wider use than that for which it was shaped at first. So I have been encouraged to make it known, in order that it may be within the reach of all who may have occasion to use it. Already it is likely to be tried in the attempt to improve and enrich the speech of deaf-mutes, which is pitifully lacking in the element of tone, chiefly because of the difficulty of conveying to the sufferers any intelligible ideas or suggestions concerning modulation of the voice.

To my colleagues of the Department of Anthropology of the University of California—Drs. Pliny E. Goddard, A. L. Kroeber, and T. T. Waterman—I am greatly indebted: to the first for the initial impulse received as I watched his work in recording Indian speech; to all of them in succession for generous and untiring assistance in securing the numerous records of the voice which formed the material of my studies; and especially to Dr. Waterman for the unfailing interest and enthusiasm with which he has followed my work—a stimulus without which I doubt whether this particular phase of that work would ever have been brought to completion.

Some years ago I chanced to call one day at the Anthropological Laboratory of the University of California, and found my colleagues there deeply engaged in study of instrumental records of Indian speech. They were kind enough to show me the Rousselot apparatus, and to illustrate its working by taking a few records of my own utterance of Siamese speech, which is my other vernacular.

My friends were interested at once in the peculiar sharp explosion (without aspiration) of my oriental *p*, *t*, and *k*, as shown in the record, contrasting strongly with the windy utterance given these consonants in our speech. But as I followed the delicate sinuous tracing of the vowels, it suddenly flashed upon me that each of those tiny waves was the record of the air-pulse from one vibration of the vocal chords; that its length was the direct measure of the time elapsed during that vibration, and consequently of the pitch of the voice at that particular instant. I knew then that I had within my grasp the definite settlement of the age-long dispute over the "tones" of oriental speech. The pitch of every portion of the vowel-note could be absolutely determined by physical measurement of those waves, and the whole movement or inflection of voice could thus be accurately plotted on paper. We then should have irrefragable demonstration of the precise nature of these "tones," instead of irreconcilable discrepancies between the sense-impressions of untrained observers on the one hand, and, on the other, the idle fancies embodied in the native tradition and nomenclature. So, with Dr. Goddard's kind help, I presently secured a series of records of each of the five "tones" of the Siamese language.[1]

[1] A number of these records are shown in Plate 1. Those used in this study were all taken at the highest speed of the apparatus, so as to facilitate measurement by giving the greatest possible length to the waves in the tracing. The working of the machine and the method of securing the records may be

Finding myself at that time too busy with my regular duties to carry this investigation further, I laid the records aside; but later, when I went abroad for a year of study in the Orient, I took the records with me. There, in the intervals of a larger quest, I found time to work out the results.

First came the measurements. The records of the various "tones" showed anywhere from 50 to 150 separate waves. At first an attempt was made to measure these one by one with a micrometer. After full trial, however, this scheme was abandoned, not so much because of the time and effort it involved, as because time and effort so spent were largely wasted. The exactness attainable by the micrometer was rendered of no avail because of the impossibility of determining with equal exactness the points between which the measurements were to be taken. For, while the larger phases of the waves were obvious enough, the determination of the exact point which should mark crest or hollow was as nearly impossible as it would be in the case of a sea-wave. So, to reduce to a minimum the inevitable errors of judgment, recourse was had to measuring the waves in small groups together, and reading the scale with a vernier-glass to the nearest hundredth of an inch.[2] Of the measurements so made, the smallest

briefly described as follows: The various air-pulses originating in the vocal apparatus are transmitted to a sensitive tympanum or drum, which in turn actuates a recording pen. Every separate impulse received by the tympanum gives the pen a slight thrust to one side, from which the elasticity of the tympanum promptly brings it back. The recording point lightly touches the surface of a sheet of smoked paper wrapped about a revolving brass cylinder driven by clock-work at a uniform rate of speed. So long as the tympanum is undisturbed by air-pulses, the point traces a perfectly straight white line around the cylinder. If one speaks into the receiver, each consonant breaks the smooth straight line for an instant into sudden and angular commotion, while the vowel-tones ruffle it into a series of regular waves which are often embroidered or fringed by delicate ripples or cusps caused by the overtones of the voice or by the resonance of the chambers of the vocal apparatus. These features of the vowel-tracings may be readily seen in the examples shown in Plate 1. Since the paper moves at a uniform rate under the recording point, the measurement of any one of the primary waves in the record will give its pitch relatively to the others; for pitch is determined by frequency of vibration.

For a fuller description of the apparatus and of its workings, see P. E. Goddard, "A Graphic Method of Recording Songs," in Boas Memorial Volume, p. 137.

[2] In the first experiments the waves were measured in groups of three. Later the number was increased to five, with no appreciable loss in accuracy. For the inflections of speech, unlike those of music, are true glides, with no abrupt steps or breaks which might be concealed or obscured under these averages. And in any case the thing sought is the general figure or pattern of the voice-inflection rather than its minute detail, which varies greatly with every utterance.

These measurements were recorded just as they were taken, without reducing them to the average of each group. Reduction was unnecessary, since in either case they represent ratios, and not concrete quantities. Furthermore, they are liable to reduction later to adjust them to the amended scheme yet to be described, and that single operation suffices for all.

in the whole series was 18 hundredths of an inch, and the largest 64 hundredths, showing a compass of a little less than two octaves.

All that now remained was to plot the results on the chart. But just how was this to be done? To this question I had so far given almost no thought, feeling sure that some form of the co-ordinate system now everywhere used in statistical work could easily be adapted to the needs of the case. But confronting the problem directly, and with no record of previous attempts to guide me, I found myself at a loss. On reflection, however, it occurred to me that since the whole purpose of this study was to secure a plotted figure which should supplement and correct the imperfect and fleeting image of the sound formed in the mind, the plotted figure must be really comparable with the mental one—must have the same essential plan and structure. That is, the two must have the same system of co-ordinates. This brought me to the question, How does the mind image pitch?

In listening to the flow of speech, it is probable that the mind does not ordinarily form any distinct image of the sensation of pitch. For the attention is then directed to the *ensemble* by which the mind recognizes words and phrases, and follows the general drift of thought rather than any one of the many separate elements which together make up the utterance.[3] Ordinarily the function of pitch in speech is a very subordinate one, being either incidental to emphasis, or suggestive of the syntactical or modal features of the utterance. So far is it from being an essential element, that it is entirely omitted in the written form of all languages except, of course, those in which voice-inflection is as truly an organic feature of words as are their vowels and consonants.[4] Within the field of speech, therefore, we shall look in vain for any clear answer to our question, How does the mind image pitch?

If, however, we turn to music, we find that in it pitch is no longer

[3] To this fact is due in large part the difficulty which European students experience in understanding and mastering the "tones" of Chinese speech. Their minds have never been trained to take note of the pitch of individual words, and therefore they never really hear it.

[4] Chinese writing represents a word in its entirety by a single ideographic symbol. The "tone" is inherent in the word itself, just as are all the other phonetic elements which together make up its complex. It therefore needs no separate indication. So far as known to the writer, the only modern language which consistently marks voice-inflection in writing is the Siamese, which, though an offshoot of the Chinese stock, spells its words phonetically and indicates the "tone" of each, either by the choice of letters in which tone is inherent, or else by diacritical marks. The accents of ancient Greek, however, were doubtless also tonal inflections essential to the right utterance of the syllable, and were undoubtedly present in speech long before it became necessary to invent marks to indicate their nature and position in the word.

subordinate or incidental, but a matter of prime importance. There is no doubt that when the mind pauses to consider the notes of music, it does actually image their tonal relations—does translate them into figures of location or of movement in space. To discover the essential features of this imaging we shall not need to have recourse to the psychological laboratory. They are plainly indicated in the terms which the speech of widely different races commonly applies to musical tones. Degrees of pitch are indicated by such terms as "high" and "low." Direction of change, or movement in pitch, are indicated by such terms as "rising," "falling," and "level." And further, wherever these terms occur, they are invariably used in the same sense. That is, notes of great frequency of vibration are always "high," and those of small frequency are always "low," and never *vice versa.*[5] The whole scheme of our musical notation is nothing but an elaborate development and enforcement of this same principle. Its "staff" is a veritable ladder on which the notes are visibly ranked according to pitch.

It should be remarked, however, that this particular usage of speech is not the only one that has been current in the world, or that is now current. And it is probably not the earliest usage, but one that has gradually won its way over the others. For example: of the three Greek accents already referred to, one was called *ὀξύς* (sharp), and another was called *βαρύς* (heavy)—terms certainly of an order altogether different from our terms "high" and "low," and apparently unrelated to each other. The third, *περισπώμενος* (twisted about), is probably of our spatial order, for it designates the circumflex tone, which first rises and then falls, and so is actually turned about upon itself. Thus it appears that at the period when the tonal features of Greek speech came to be matters of thought and reflection, three separate analogies were already in the field, and each furnished one of the names then given to them. But it is significant that later still, when it became necessary to mark these inflections in writing to save them from being lost, the three marks were all of one system, and that

[5] Since there seems to be nothing either in the physics of sound or in the nature of the mind to bring about this unanimity, it must be ascribed to some very early and widespread convention based, perhaps, on some external and incidental thing in musical art, such, for example, as the relative positions in which the various notes of some primitive musical instrument were produced or played. One can easily imagine that the particular instrument was the pipe, a thing of immense antiquity, and still in use throughout the greater part of the world. It is, in fact, nothing but a whistle with a tube long enough for finger-holes, and played in the flageolet position. The notes lowest in pitch are thus sounded from the openings which are lowest in actual position, and those higher in pitch, from openings higher up on the tube.

one is our own of spatial representation. For the marks are really nothing but tiny diagrams of the gestures by which one might instinctively illustrate the three movements in pitch: / rising, \ falling, ⌒ circumflex. "Sharp," the equivalent of the Greek term ὀξύς, still survives as a technical term in modern music for a note slightly raised in pitch; but its counter-term "flat" seems to be a recent invention, the logical basis of which is not clear.

We have turned from the field of speech to that of music because only in music have the phenomena of pitch received the full attention necessary to the formulation of a usage which clearly reveals the workings of the mind in dealing with this matter. The usage of music shows that the modern mind at least has learned to visualize pitch spatially, as position on a vertical scale, with notes of shorter vibration above, and notes of longer vibration below.

But pitch is not the only thing to be provided for in our scheme. Inflection of the voice has also the element of movement and change, and these can take place only in time. The chart must provide also for this other dimension, time. Fortunately there is here no difficulty, for the mind habitually co-ordinates space and time, and readily translates either one of these into terms of the other. It images time as the track of a moving point—that is, as a line. Unless otherwise determined by outside circumstances, the movement seems generally figured as horizontal, and from left to right across the field.[6]

The results of this excursus into the realm of psychology may be summed up as follows. The essential elements of the mental image of an inflection of the voice are two: pitch and time. Pitch is figured as position attained at a given instant on a vertical scale. Time is figured as advance from point to point measured on a horizontal scale. The inflection itself is figured as a line which is the resultant of these two components.

These principles determined the general scheme of the chart to be as follows: The series of numbers derived from measurements and representing the various levels of pitch, are the vertical elements of the chart, that is, its ordinates; and numbers representing the time-intervals are the horizontal elements, that is, its abscissas.

There still remained the problem of spacing in both these dimen-

[6] Both these features are doubtless due to convention—perhaps both to the same convention, namely to the direction taken by Indo-European writing. Both are abundantly attested by our modern cartographic treatment of all statistical matter involving the element of time. In antiquity we find the same idea reflected in the Greek accent-marks already alluded to. How Arabians and Chinese image time I am unable to say.

sions. Following the common practice in the plotting of statistics, the spacing was made uniform throughout each of these dimensions, but not alike in both. Unit-spaces on the co-ordinate paper were assigned to the vertical series of measurement-numbers representing the various levels of pitch;[7] and a constant small interval, sufficient to give the requisite spread to the figure and to bring out its features, was chosen, after experiment, as the horizontal time-interval of advance between successive stations on the chart.

This scheme was carried out as follows: Beginning at the left-hand margin, the first measurement was entered as a pencil-dot at the beginning of the line which bore its number. The second was next entered upon its own numbered line, but advanced toward the right by the interval determined upon. The other measurements followed in their order, each on its own numbered line and at the same constant interval to the right, till all the measurements of that particular record were plotted. A continuous curving line was then drawn through the series of plotted points, and the figure so completed represented visually the whole movement or inflection of the voice in uttering that syllable.[8] In like manner the four other "tones" of the series were plotted upon the same sheet. Finally the whole was brought into approximate relation with concert-pitch by finding on a piano the pitch at which I habitually sounded the more level stretch of the "middle tone"—which was F. From this the positions of the other notes of the diatonic scale were computed by the help of the well-known ratios of the musical intervals,[9] and their places were marked upon the margin. So far as I can ascertain, this was the first attempt ever made to plot from measurements the inflections of the human voice. The chart was completed in November, 1908, and was exhibited at a public meeting of the Siam Society in Bangkok on February 2 following.

The experiment was more successful than I had dared to hope. The results were perfectly clear and convincing. The general scheme was evidently right. Careful study, however, revealed a certain distortion of vertical values which interfered with accurate comparison of one of these figures with another in a different portion of the field —a distortion in kind not unlike the horizontal distortion of Mercator's

[7] In this case the measurement-numbers ran from 18 at the top of the sheet to 64 at the bottom. Cf. plate 2 and p. 198 *ante*.

[8] The figure so plotted is the rising glide shown in plate 2, which is a reproduction of my original chart published in the Journal of the American Oriental Society, XXXI, pt. 3, p. 286. 1911.

[9] Cf. Century Dictionary *s. v.* Interval.

maps. The source of it was found to be the equal spacing of the vertical series of numbers representing the levels of pitch. While these numbers increase from above downward in arithmetical progression, the musical intervals, as plotted on the chart, increase in geometrical progression, with the result that any given interval of the lower octave occupies a vertical space just twice as great as the same interval of the upper octave. An upward sweep of an octave from middle pitch would appear only half as long as a descending sweep of an octave from the same starting-point. This distortion is brought out unmistakably if one compares the rising glide in plate 2 with the falling one. The rising glide covers fourteen semitones, while the falling one covers six and one-half. Yet on the chart the vertical reach of the former is only a trifle greater than that of the latter.[10] The distortion would be very much greater if voices of entirely different range, such for example as the masculine and the feminine, were plotted together according to this scheme and brought into comparison. In such a case, indeed, effective comparison would be almost impossible.

Now the ear knows nothing whatever of measurements such as we have been making; but beyond question it recognizes all octave cycles as equal. Whether this is due to the recognition directly by the ear of cycles of recurrent unison, or whether it was first suggested by the fact that, in instruments like the pipe, the upper and the lower octaves are played from the same openings and over the very same length of tube, are questions which need not detain us here. But if the octaves are equal, then it follows inevitably that the semitones—if they be equal divisions of the octave—are all equal to each other. This equality, moreover, is enforced by the almost universal use of the tempered scale for musical instruments played either with keys or with frets. Thus our visual imagination and our thought too, unless sophisticated by physics, follow suit of the ear and make the semitones equal.

The error being thus located, the first step toward rectifying it was obvious and easy, namely, to make the semitone-intervals equal

10 This element of vertical distortion, coupled with another of horizontal distortion to be noticed later, may also be clearly seen if one compares figure 1 of plate 5, where both errors are uncorrected, with figure 2 of the same plate, where both are eliminated. The vertical element works as gravity does, progressively diminishing all upward movement as represented on the chart, making it fall short of its due height; and progressively increasing all downward motion, making it overshoot its mark. The other (the horizontal) distortion gives to ascending motion a greater spread than is its due, and to descending motion a spread proportionately less. The two together make the plotted figure of the rising inflection both shorter and flatter than it should be, and that of the falling inflection both deeper and steeper.

upon the chart. So the symbols of the twelve semitones took the places previously occupied by the measurement-numbers on the unit-lines of the paper. But the next step—to find new places for those ousted numbers—was not by any means so easy. Indeed, it was long before any clear lead appeared. After much vain groping it suddenly flashed upon me one day that each semitone of the octave has its distinct numerical value, namely, its ratio to the fundamental note of the scale. And this numerical value it brings with it to the new position in which it has been placed. These decimal ratios of the semitones therefore, equally spaced, form the determining series of the corrected chart, in the intervals of which the integers of the measurements must be interpolated, each in its proper place. I had found the clew, but was by no means out of the labyrinth.

The ratios of the diatonic scale already mentioned would not answer here, for their intervals are not equal. I was where no books of reference were accessible, and I am not at all sure that I should have found what I wanted, if I had had them. Thrown back thus upon my own resources, I reflected that the octave ratios form a series in geometrical progression—1, 2, 4, 8, 16, and so on—with the constant ratio of 2. The semitone-ratios of the tempered scale, therefore, must also form a geometrical progression of twelve terms *within* each octave. Since 2 is the constant ratio of the octave series, the constant ratio of the semitone series must be that quantity which multiplied into itself twelve times will make 2—that is, the twelfth root of 2. Fortunately my desert island afforded an article of furniture not often found in such places—a table of logarithms. With its help I soon worked out the series of ratios shown on the left-hand margin of plate 4 and in table 1 below. For convenience in plotting, and to get rid of a decimal place, 10 rather than 1 was assumed as unity. The computation covered two octaves—twenty-four semitones—with numerical values ranging from 10 to 40, providing compass enough for any ordinary speaking voice in experiments such as these.

The earlier scheme, it will be recalled, was concrete and practical, based on a series of numbers derived from actual measurements. This new scheme was begun with an ideal series of ratios, and I proceeded to work it out as an ideal scheme to the end, leaving to a later stage the question of its adjustment to concrete cases. So dealing with it, the problem of interpolation referred to above became a problem of finding the places, within this ratio-series, of the natural numbers from 10 to 40. The ratios are mostly decimal, though 10, 20, and 40 at the octave points are integers, and two others, at the fifth below in each octave, differ but infinitesimally from 15 and 30. Five numbers were thus located at the start, and the particular space within which each one of the other numbers must be located was plainly disclosed. Their exact positions, however, were not so easily determined. The method of proportional parts was first tried, and it furnished an approximation sufficiently close to serve the purpose immediately in view. Indeed, that was the method used in plotting the "tones" of Chinese speech.[11]

Here I should have stopped. But the "pagan curiosity" with which I am sometimes reproached drove me on. There must be a *real* solution to a mathematical series so wonderfully strict and symmetrical; and I must find it. Nevertheless I groped long in darkness before light broke upon me at last one morning as I awoke out of sleep. If I were to plot the curve of those semitone ratios, the levels at which the curve cuts the vertical unit-lines would be the true location of the integral numbers. Without delay I set myself to work. The result is shown in plate 4, figure 1, where the vertical distances (ordinates) of the integer levels may be read directly from the millimeter divisions of the paper.

Even so I was not satisfied. The solution was perfect of its kind, but the kind was instrumental and mechanical—not of pure science. I marvel now at my infatuation with the problem, but still more at my stupidity. Long before this, in computing the semitone-ratios, I had used—without recognizing it or so formulating it—the equation $y = a^x$, wherein $a$ is $\sqrt[12]{2}$, and $x$ is in turn each of the numbers of the natural series from 1 to 24. But the equation is really one of *two* variables. All that I now needed to do was to turn the equation about and solve it for the values of $x$ when, $a$ remaining constant, $y$ is in turn each number of the natural series from 10 to 40. This all the time being within my reach, and with the diagram fully drawn and under my eyes, it was weeks before I recognized in it the solution I was seeking. Thus at last my calculus, fifty years out of mind, came back to me and laid the uneasy demon that so long had plagued me.

The distortion of figure, in so far as it arose from the unequal spacing of the semitone intervals, was now completely corrected by respacing unequally the numbered levels of pitch in such a way that

[11] Cf. plate 3, from a chart first published in Proceedings of the American Philological Association, XLV, page xliv, with abstract of the paper read. The paper was subsequently published in full in the Journal of the Royal Asiatic Society, North China Branch, August, 1915.

their intervals diminished from above downward just fast enough to leave the semitone intervals equal throughout the chart. Still another element of distortion, however, lurked in the equal horizontal spacing which was adopted at the start. The spaces there *ought* to vary also, for they represent the time-intervals between successive points in the record, and these vary of course with the pitch. It was some time, I am ashamed to say, before it became clear that the very same measurement which I plotted vertically as pitch, gave me also, in its aspect as time, the measure of forward movement. The single measurement, that is, gives both co-ordinates of the plotted point—a most unusual and surprising thing.

It must not be supposed, however, that the whole of the measurement-number must be taken as the increment of advance. To do so would be to flatten the figure almost beyond recognition. All that is necessary is that the increment in each case be proportional to the number representing pitch. Some constant fraction of that number —say one-half or one-third—will suffice to give the figure the necessary spread.

Reviewing now the discussion so far, we see that the general scheme for plotting inflections of the voice involves two dimensions, each with a different system of spacing. In the scheme as originally worked out, there was an error of distortion in each of these two dimensions, due to the equal spacing which was tentatively adopted in each. In the readjustment of the scheme described above both errors have been eliminated by substituting for the equal spacing in each dimension a spacing graduated proportionally to the measurement-numbers—inversely proportional in the case of the vertical intervals; directly proportional in the case of the horizontal. Inflections so plotted are capable of strictest comparison in all their features both with each other and with the records. It is difficult, moreover, to see how any other systematic error can creep in, for there are but these two dimensions in which it could operate, and but the one door of measurement by which it could enter.

The revised scheme, as has been noted, is not built upon actual measurements, as was the first one, but upon an ideal system of abstract numbers or ratios, on the one hand, and of positions determined by these, on the other. It is, moreover, limited to two octaves, a compass which includes the extreme range of voice in ordinary speech. The special advantage of such a scheme is that, being ideal, it is capable of being adapted without difficulty to any concrete case. The essential feature of the plot (that is, the spacing of the numbered levels of pitch) is arranged once for all, and is never to be changed. Adjustment has to do only with the numbers which are attached to these levels, and it may be accomplished in either of two ways: (*a*) the numbers of the scheme may be raised to meet the actual measurements by use of a suitable multiplier, or (*b*) the measurement-numbers may be reduced by division to the dimensions of the scheme. There is little to choose between the two methods, save that there is probably less chance of mistake or confusion if the plotted scheme of numbers be kept unchanged, and the particular voice or the particular measurements be reduced to the standard, just as all barometric readings, for purposes of comparison, are reduced to sea-level. The whole process may be made clear by means of the following example together with its illustration in figure 2 of plate 4.

In table 3, column 2 (p. 207), are given two series of measurements made in the course of my experiments with the "tones" of Siamese speech. The two are taken almost at random from my notes, and represent respectively the rising and the falling inflection. The measurements are of groups of six waves throughout. The extreme measurements are 30 and 110—a large compass of voice, falling only a little short of two octaves. The smallest number in our scheme is 10. The measurements may therefore be reduced to standard by dividing them throughout by 3. The results of the reduction are tabulated in column 3, and these are the figures to be used in the plotting.[12]

In table 2, column 1, are given the numbers attached to the levels of pitch in our scheme; and opposite these in column 2 are given the ordinates of those levels, that is, the vertical distance of each measured from the starting-point at level 10 at the top of the sheet. These ordinates are the results of the computation described above (p. 204).

We turn now to the co-ordinate paper on which the inflections are to be plotted. Vertically it should have twenty-four unit spaces—one for each semitone of the two octaves. Horizontally, the eighteen unit spaces usually found in the millimeter sheet will be ample for all needs.

Beginning at the upper right-hand corner, we number each unit-line along the margin from 0 at the top to 24 at the bottom. This marking has nothing to do with the final plot and is not absolutely

[12] In many cases it may be found simpler to perform the reduction by multiplying and pointing off one decimal place. Thus, if the extreme measurements had been 27 and 95, we might have multiplied by 4 and pointed off thus: 10.8 and 38.0.

necessary, but is only intended to facilitate the reading of the millimeter distances in the next operation. It should be done lightly with a pencil, so that it may be easily erased when it has served its purpose. It therefore does not appear in plate 4.

Next, at a little distance within the right-hand margin, we mark the top line 10, the level with which our scheme begins. Its distance of course is zero. From table 2 we take the second distance, 16.5, and find its place between the 16th and 17th millimeter lines directly below 10, where we mark it with a short horizontal pencil-line, and number it as level 11. We find in the table the third distance, 31.6 (measured also from line 10), and with the help of the marginal numbering of the unit-lines, we enter it in its place as level 12—and continue the operation with constantly diminishing spaces, until we reach the 40th level at the 24th line near the bottom. This completes the preparation of the chart.

TABLE 1

The Semitone Ratios

| No. | Numerical Value |
|---|---|
| 0 | 10.00 |
| 1 | 10.60 |
| 2 | 11.23 |
| 3 | 11.89 |
| 4 | 12.60 |
| 5 | 13.35 |
| 6 | 14.14 |
| 7 | 14.98 |
| 8 | 15.87 |
| 9 | 16.81 |
| 10 | 17.81 |
| 11 | 18.87 |
| 12 | 20.00 |
| 13 | 21.20 |
| 14 | 22.46 |
| 15 | 23.78 |
| 16 | 25.20 |
| 17 | 26.70 |
| 18 | 28.28 |
| 19 | 29.96 |
| 20 | 31.74 |
| 21 | 33.60 |
| 22 | 35.62 |
| 23 | 37.74 |
| 24 | 40.00 |

TABLE 2

The Levels of Pitch

| No. | Vertical Distance |
|---|---|
| 10 | 00.0 mm. |
| 11 | 16.5 |
| 12 | 31.6 |
| 13 | 45.5 |
| 14 | 58.3 |
| 15 | 70.3 |
| 16 | 81.5 |
| 17 | 92.0 |
| 18 | 101.8 |
| 19 | 111.1 |
| 20 | 120.0 |
| 21 | 128.5 |
| 22 | 136.5 |
| 23 | 144.2 |
| 24 | 151.6 |
| 25 | 158.7 |
| 26 | 165.5 |
| 27 | 172.1 |
| 28 | 178.3 |
| 29 | 184.3 |
| 30 | 190.3 |
| 31 | 196.0 |
| 32 | 201.5 |
| 33 | 206.9 |
| 34 | 212.0 |
| 35 | 217.0 |
| 36 | 221.8 |
| 37 | 226.5 |
| 38 | 231.1 |
| 39 | 235.6 |
| 40 | 240.0 |

TABLE 3

Measurements

Series 1

| No. | Original | Reduced | Horizontal Interval |
|---|---|---|---|
| 1 | 56 | 18.7 | 9 mm. |
| 2 | 55 | 18.3 | 9 |
| 3 | 56 | 18.7 | 9 |
| 4 | 55 | 18.3 | 9 |
| 5 | 54.5 | 18 | 9 |
| 6 | 53.5 | 17.8 | 9 |
| 7 | 51 | 17 | 9 |
| 8 | 50 | 16.7 | 8 |
| 9 | 48 | 16 | 8 |
| 10 | 46 | 15.3 | 8 |
| 11 | 43 | 14.3 | 7 |
| 12 | 40 | 13.3 | 7 |
| 13 | 37 | 12.3 | 6 |
| 14 | 36 | 12 | 6 |
| 15 | 35.5 | 11.6 | 6 |
| 16 | 35 | 11.5 | 6 |
| 17 | 33 | 11 | 6 |
| 18 | 30 | 10 | 5 |
| | Series 2 | | |
| 1 | 50 | 16.7 | 8 mm. |
| 2 | 52 | 17.3 | 9 |
| 3 | 54 | 18 | 9 |
| 4 | 56 | 18.7 | 9 |
| 5 | 57 | 19 | 10 |
| 6 | 58 | 19.3 | 10 |
| 7 | 61 | 20.3 | 10 |
| 8 | 66 | 22 | 11 |
| 9 | 74 | 24.7 | 12 |
| 10 | 83 | 27.7 | 14 |
| 11 | 93 | 31 | 16 |
| 12 | 110 | 36.7 | 18 |

We come now to the actual plotting. Referring to table 3 for the reduced measurements (in column 3) we take the first one, 18.7, and enter it with a pencil-dot slightly above level 19 traced across the chart. Taking the next number, 18.3, we note its place just below level 18; and finding in column 4 its horizontal interval, 9 (one-half of 18.3), we enter the second point at the level ascertained, and 9 millimeter spaces to the right of the first. The third point is again on level 18.7, and 9 mm. to the right of point 2. This process is continued until the series ends with point 18 at level 10, 126 mm. from the left-hand edge. Through this series of points a smoothly curving line is carefully drawn, which constitutes the figure or pattern of movement executed by the voice in that particular utterance.

The plotting of the second series of measurements is carried out in the same way, and on the same sheet. Lastly, concert-pitch is found from the record of a C-fork taken at the same time with the other records, which in this case determines the level of C as 17.6, that is, near the 10th unit-line from the top. From this datum the places of the other notes of the musical scale are easily determined by assigning one unit-space to each semitone.

This study demonstrates the immense superiority, in point of delicacy, of instrumental analysis over the trained ear. In plate 3, tone 1, are shown five examples of the utterance of the same short syllable in succession. The pitch was intended to be a perfectly level tone. The serpentine oscillations which our analysis reveals entirely escaped the sense of hearing, as did also the uncertainty of attack and finish, and the hesitation in mid-movement exhibited in many examples of other tones given in the same chart. In figure 3 of plate 5 may be seen the vagaries of a singer's voice in rendering C natural—a continual wandering away from pitch followed by attempted correction and return. The ear fails utterly to detect errors of this dimension, for the whole portion of the note here shown on the chart occupied but 1.08 of a second of time. The instrument reveals even minute variations in the rate of a tuning-fork due to infinitesimal variations in the drag on the prongs of the fork as the recording point sweeps the surface of the paper.

*Transmitted April 3, 1916.*

## EXPLANATION OF PLATE 1

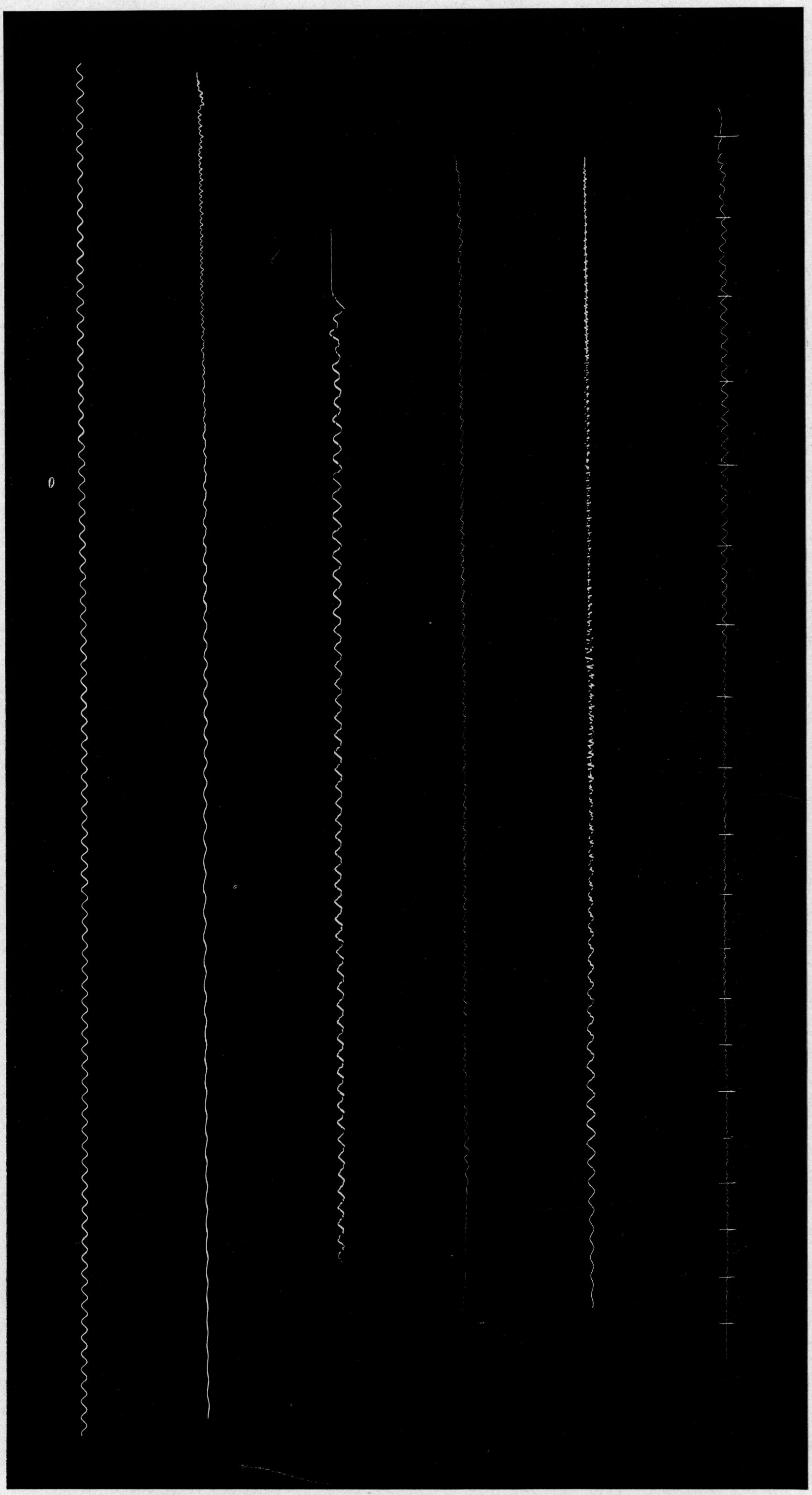
Specimen records taken with the Rousselot apparatus, reduced to three-fourths of their original dimensions.

Numbers 1 to 5 are records of the five ''tones'' of long vowels in Siamese speech, namely, 1, Rising; 2, Circumflex; 3, Middle; 4, Depressed; 5, Falling. No. 1 has been marked off into groups of waves for measurement. Number 6 is the record of an electric tuning-fork making 100 vibrations per second.

The general features of movement and pitch which characterize these five ''tones'' are shown in plate 2; and a brief indication of the part they play in actual speech is given in the explanation of that plate. For an account of the way in which the records are made, see footnote 1, pp. 196–197.

The extreme delicacy of which these records are capable is shown in the case of the electric fork, the rate of which would naturally be supposed to be absolutely uniform within the limits of a single record. But measurement shows that the rate varied during the fraction of a second of time occupied in the process. The first forty waves of the record together measure two one-hundredths of an inch more than the last forty. This infinitesimal variation is probably due to infinitesimal differences in the drag of the recording point as it swings from side to side on the surface of the paper.





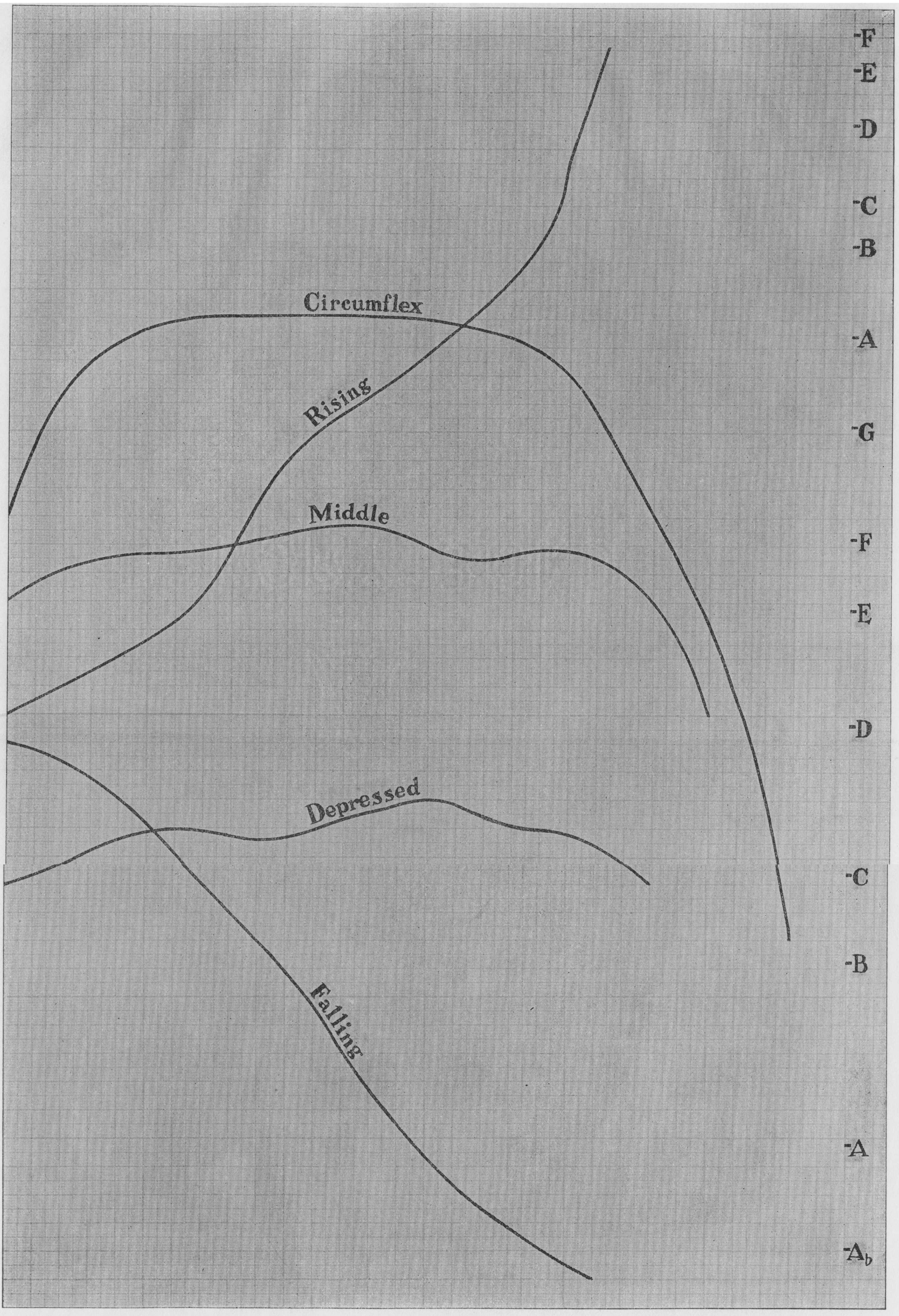
## EXPLANATION OF PLATE 2

Chart of the five ''tones'' of long vowels in Siamese, illustrating the earlier scheme of plotting.

So far as known to the writer, this is the first attempt ever made to plot from actual measurements the inflections of the voice. It was made in November, 1908, and was exhibited at a meeting of the Siam Society held in Bangkok on February 2, 1909.

The figures here shown were plotted from records of the writer's voice as he pronounced the one syllable *nā* with the five modes of voice-inflection distinguished by the Siamese in their utterance of long vowels. The one syllable so uttered becomes five different words, which to the natives do not seem to be homophones at all, but as clearly different as seem to us the words *bate, beat, bite, boat, boot,* which differ only in vowel quality. The meaning of the five Siamese words, differing only in tone, are as follows:

| *Syllable* | *Inflection* | *Meaning* |
|---|---|---|
| *nā* | rising | *thick* |
| | circumflex | *uncle* or *aunt* |
| | middle | *rice-field* |
| | depressed | *indeed* |
| | falling | *face, front* |



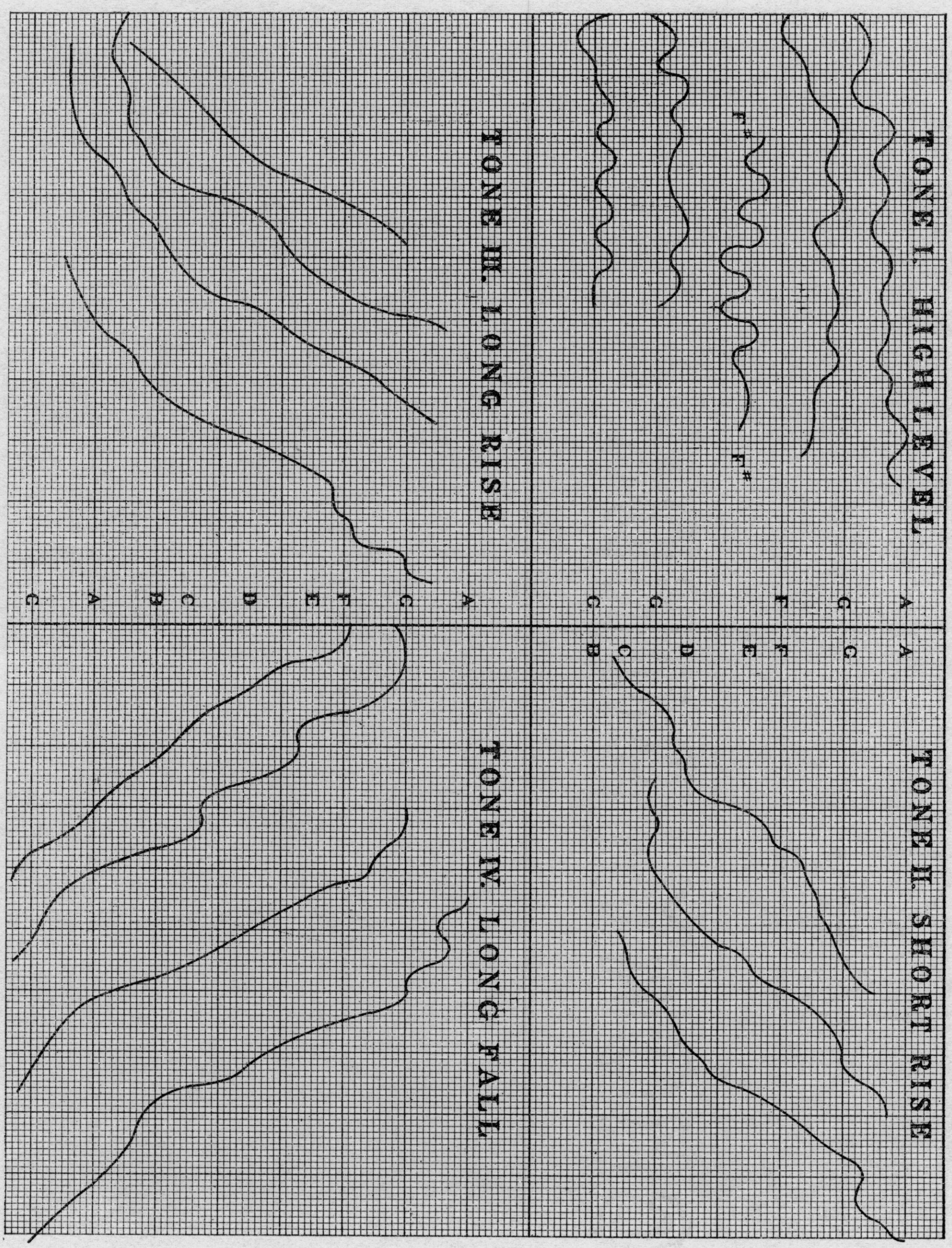
## EXPLANATION OF PLATE 3

Chart of the ''tones'' of Pekingese.

In this chart the vertical distortion noted in the earlier scheme was corrected by giving to the levels of pitch a graduated instead of a uniform spacing. It has a further interest in its revelation of surprising eccentricities or inaccuracies in the performance of the human voice. Tone 1, for example, is heard by the ear as a tone perfectly level in pitch. Its serpentine oscillations completely escape notice by the ear, as do also the uncertainty of attack and the hesitation in execution noticeable in many other figures of the chart.

Pekingese scholars claim four separate ''tones'' for their dialect. But the chart would seem to show that there are really but three. The general figure or pattern of ''tone'' 2 is identical with that of ''tone'' 3, and instrumental analysis fails to discover within the range of examples available any constant difference of detail which the ear could detect as a basis of distinction. It may be that there is a difference in vowel-quantity which does not appear in the examples chosen.

UNIV. CALIF. PUBL. AM. ARCH. & ETHN. VOL. 12 [BRADLEY] PLATE 3

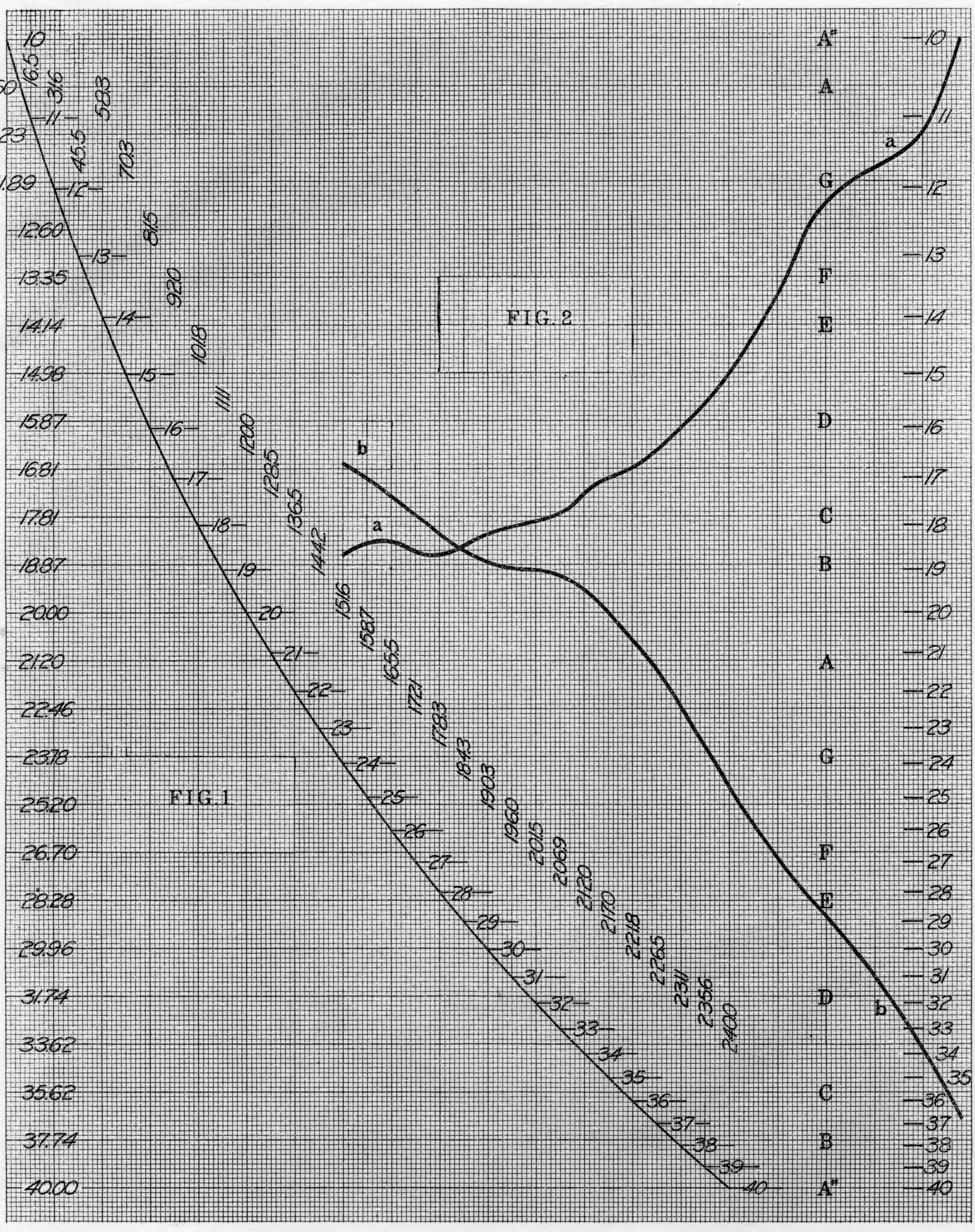


## EXPLANATION OF PLATE 4

Figure 1.—The semitone-ratios and the levels of pitch.

The semitone-ratios are a series of numbers which express the relative time of vibration at the pitch of each semitone of the octave, when the vibration-time at the pitch of C is 10. These ratios, computed for two octaves, are shown at the left-hand margin of the chart, each on its unit-line. The ratios, it will be noted, are nearly all decimal. The problem is to find the precise levels within this decimal series at which the integers 11, 12, 13, etc., are to stand. The problem was solved graphically as follows: Each ratio (less 10, because we begin at the margin with 10) was plotted on the chart as a horizontal line. Through the ends of these lines a curve was drawn. The points in which this curve cuts the vertical unit-lines will mark the true levels of the various integral numbers. The vertical distance (ordinates) from 0 at the top of the chart to each of these levels may be read directly from the co-ordinate paper. The ordinates actually entered on the chart are those derived from a subsequent computation, and are carried out to one decimal place.

Figure 2.—Illustration of the perfected scheme for plotting inflections without distortion in either dimension. aa is the figure of a rising inflection, and bb the figure of a falling inflection so plotted. For the data used and for detail of the method see table 3 and the adjacent text, p. 207, *ante*.

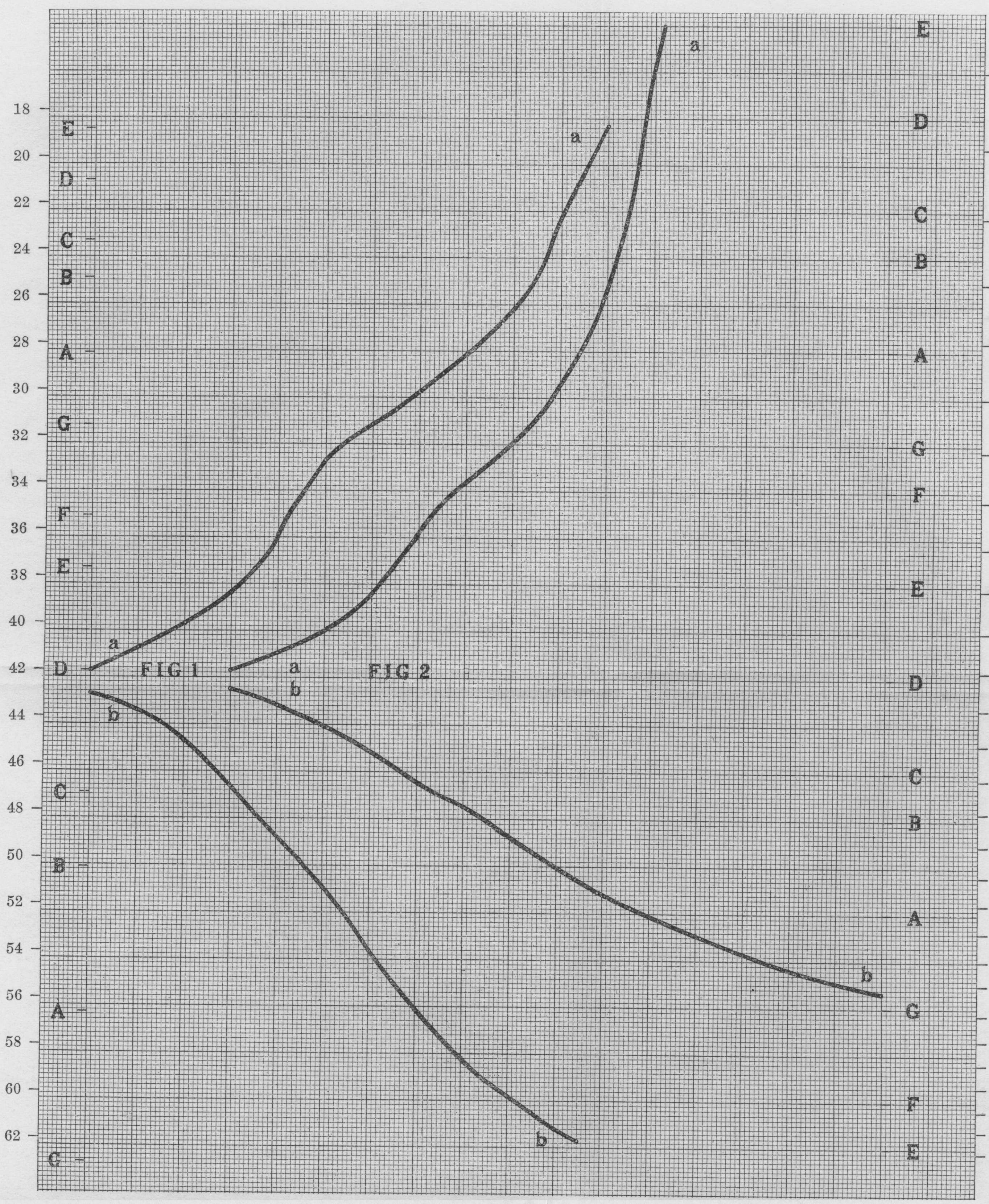


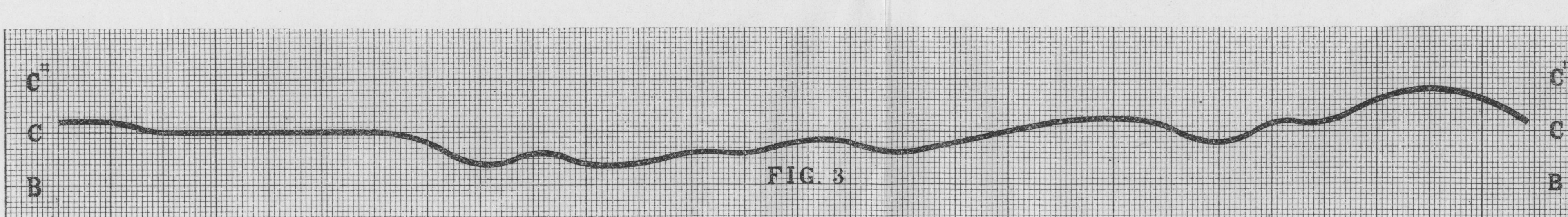
## EXPLANATION OF PLATE 5

Figures 1 and 2.—Direct comparison of the two schemes of plotting.

Figure 1 is the rising inflection (aa) and the falling inflection (bb) as originally plotted in plate 2. Figure 2 shows these same inflections replotted according to the perfected scheme. Comparison shows that aa of figure 1 is shorter and flatter and shows a greater time-dimension than does the corrected aa of figure 2, while bb of figure 1 is deeper, steeper, and has less time-dimension than the corrected bb of figure 2.

Figure 3 is a representation of the performance of a singer's voice in rendering the C natural of a tuning-fork. It illustrates the same vagaries, the same uncertainties and attempted corrections which were shown in the case of the speaking voice in plate 3.



Volumes now completed:

| | | |
|---|---|---|
| Volume 1. | 1903-1904. 378 pages and 30 plates | $4.25 |
| Volume 2. | 1904-1907. 393 pages and 21 plates | 3.50 |
| Volume 3. | 1905. The Morphology of the Hupa Language. 344 pages | 3.50 |
| Volume 4. | 1906-1907. 374 pages, with 5 tables, 10 plates, and map | 3.50 |
| Volume 5. | 1907-1910. 384 pages, with 25 plates | 3.50 |
| Volume 6. | 1908. 400 pages, with 3 maps | 3.50 |
| Volume 7. | 1907-1910. 443 pages and 50 plates | 3.50 |
| Volume 8. | 1908-1910. 369 pages and 28 plates | 3.50 |
| Volume 9. | 1910-1911. 439 pages | 3.50 |
| Volume 10. | 1911-1914. 385 pages and 41 plates | 3.50 |

Note.—The University of California Publications are offered in exchange for the publications of learned societies and institutions, universities and libraries. Complete lists of all the publications of the University will be sent upon request. For sample copies, lists of publications or other information, address the Manager of the University Press, Berkeley, California, U. S. A. All matter sent in exchange should be addressed to The Exchange Department, University Library, Berkeley, California, U. S. A.

**AGRICULTURAL SCIENCES.**—E. B. Babcock, J. W. Gilmore, and C. B. Lipman, Editors. Price per volume, $3.50. Volumes I and II in progress.

**ASTRONOMY.**—W. W. Campbell, Editor. (Lick Observatory, Mt. Hamilton, Cal.) Publications of the Lick Observatory.—Volumes I-XII completed.

**BOTANY.**—W. A. Setchell, Editor. Price per volume $3.50. Volumes I (pp. 418), II (pp. 360), III (pp. 400), and IV (pp. 397) completed. Volumes V and VI in progress.

**CLASSICAL PHILOLOGY.**—Edward B. Clapp, William A. Merrill, Herbert C. Nutting, Editors. Price per volume $2.00. Volume I (pp. 270) completed. Volume II in progress.

**EDUCATION.**—Edited by the Department of Education. Price per volume $2.50.

**ENGINEERING.**—Edited under the direction of the Engineering Departments. This series will contain contributions from the Colleges of Mechanics, Mining, and Civil Engineering. Volume I in progress.

**GEOGRAPHY.**—Ruliff S. Holway, Editor. Volume I in progress.

**GEOLOGY.**—Bulletin of the Department of Geology. Andrew C. Lawson and John C. Merriam, Editors. Price per volume $3.50. Volumes I (pp. 435), II (pp. 457), III (pp. 482), IV (pp. 462), V (pp. 458), VI (pp. 454), VII (pp. 504), and VIII (pp. 583) and IX (pp. 534, index in press) completed. Volume X in progress.

**MODERN PHILOLOGY.**—Volumes I (pp. 400) and II (pp. 373) completed. Volumes III and IV in progress.

**PATHOLOGY.**—Frederick P. Gay, Editor. Price per volume, $2.50. Volume I (pp. 347) completed. Volume II in progress.

**PHILOSOPHY.**—G. H. Howison, Editor. Volume I (pp. 262) completed. Volume II in progress. Price per volume $2.00.

**PHYSIOLOGY.**—S. S. Maxwell, Editor. Price per volume $2.00. Volumes I (pp. 217), II (pp. 215), III (pp. 197), and IV (pp. 228) completed. Volume V in progress.

**PSYCHOLOGY.**—George M. Stratton, Editor. Volumes I and II in progress.

**ZOOLOGY.**—W. E. Ritter and C. A. Kofoid, Editors. Price per volume for volumes I-X, $3.50; for volume XI and following, $5.00. Volumes I (pp. 317), II (pp. 382), III (pp. 383), IV (pp. 400), V (pp. 440), VI (pp. 478), VII (pp. 446), VIII (pp. 357), IX (pp. 365), X (pp. 417), and XI (pp. 538) completed. Volumes XII to XVII inclusive in progress.

**UNIVERSITY OF CALIFORNIA CHRONICLE.**—An official record of University life, issued quarterly, edited by a committee of the Faculty. Price, $1.00 per year. Current volume No. XVIII.

Address all orders or requests for information concerning the above publications to The University of California Press, Berkeley, California.