Nature of Vowel Sounds.

By PROF. E. W. SCRIPTURE.

The Analysis of Vowel Curves.

SINCE the time of Wheatstone and Helmholtz the vowels have been almost universally supposed to obtain their tones by acting as resonators to certain overtones of the larynx tone. Helmholtz even constructed an apparatus of a set of harmonic tuning-forks by combinations of which he hoped to produce the vowels. Ever since the invention of the speech-recording machine by Scott and Koenig in Paris the analysis of vowel curves has been expected to solve the problems of the nature of a vowel and of the differences between different vowels.

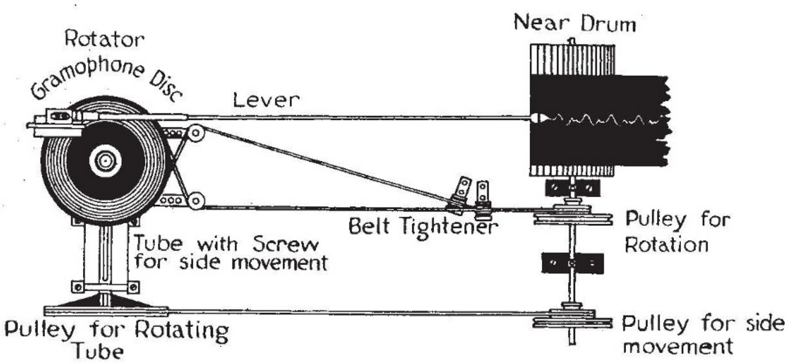

FIG. 1.—Apparatus for tracing gramophone curves. A steel needle near one end of a long lever follows the groove. Its movements are enlarged 500 times and registered on a band of smoked paper.

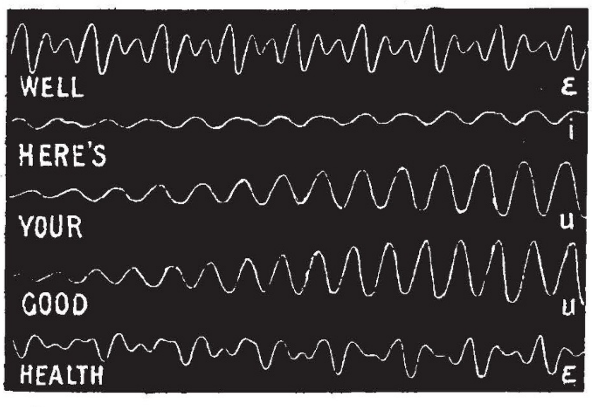

FIG. 2.—Vowel curves. The waves fall into groups; the top line contains eight groups, the next line six, the third seven, the fourth eight, and the last seven. Each group corresponds to one vibration from the larynx. The length of a group gives the pitch of the laryngeal tone; in speech this is always rising or falling. The height of the waves indicates the intensity. This is nearly always small at the beginning of a vowel; there is a steady rise to a maximum and then usually a fall to the end. The small waves within a group give the characteristics of the vowel sound. The top line is a piece out of the middle of the vowel in "well." The second line is from the vowel in "here." The third is near the beginning of "your." The fourth is the first part of the vowel in "good." The last is from the middle of "health." In the second, third, and fourth cases there is evidently present a tone more or less nearly the octave of the laryngeal tone. The other tones and the tones in the other cases can be found only by analysis.

At the present day the vowels can be recorded on talking machines, and their curves can be traced off with an accuracy that leaves nothing to be desired. The work of Hermann on the curves of the vowels and consonants by means of the phonograph is still unsurpassed. For my own investigations the gramophone was chosen as the most available machine.

A disc with the desired record was placed on a very slowly revolving plate (Fig. 1). A long lever of Japanese straw was held in an axle at one end. Near this end a steel point projected downward into the speech groove. At the other end there was a recording point made of a fine glass thread. As the disc revolved, the movements were magnified—up to 500 times—and traced on a moving band of smoked paper.

Pieces of vowel curves cut out of a tracing of a record by Joseph Jefferson are shown in Fig. 2. The curves show that in speech the vowels change constantly in pitch, in intensity, and in character. They also show that the vowels actually used in speaking are often not what the phonetician supposes them to be.

The point of interest on the present occasion, however, is the nature of a single wave of a vowel. At the present day there is only one way of analysing a wave—namely, the harmonic analysis. Any wave can be represented as made up of a series of simple sine waves with the relations of frequency of 1 : 2 : 3 : . . . and with various amplitudes. A harmonic analysis of the wave in the top line of Fig. 3 gives the four curves in the lines below. This means that the four curves, if added together, will give a result like that in the top line.

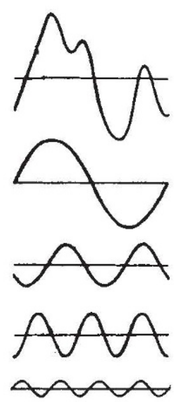

FIG. 3.—A curve composed of four sinusoids.

Suppose, now, that we have a curve that consists of a vibration repeating itself every $3\frac{1}{2}$ times to a wave. The harmonic analysis gives as result a fairly strong fundamental of the frequency 1, a stronger vibration of the frequency 2, a still stronger vibration of the frequency 3, a somewhat less strong vibration of the frequency 4, and ever-lessening vibrations of the frequencies 5, 6, 7, etc. Not one of these vibrations was actually present in the original curve. The strength of the original vibration of $3\frac{1}{2}$ could not be directly given, because there was no place for it in the harmonic series.

The harmonic analysis shows us how a given curve can be represented as made up of a series of harmonic components; it does not say that it was originally so produced. Such a deduction has to be made on other grounds. The familiar experiment with a piano string touched lightly in the middle, then at one-third of its length, etc., shows that it vibrates in harmonic parts; an analysis that gives the harmonic components in various amplitudes can be accepted at once as indicating the strength of the components. An analysis, however, that gives all the harmonics as being present to some degree with a bunch of strong ones at one or more points would indicate at once that one or more inharmonics were present.

A harmonic analysis of the wave in Fig. 4 from the first vowel in "Marshall" gives the harmonic plot shown in Fig. 5. This merely states that the original wave can be reproduced by using harmonics in the relations indicated. The deduction concerning how the wave was originally produced is left for the person who interprets the harmonic plot.

If such a result were obtained for a wave from a musical orchestra, we should have no hesitation

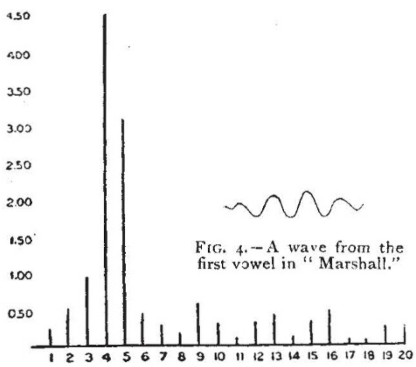

FIG. 4.—A wave from the first vowel in "Marshall."

FIG. 5.—Relative amplitudes of the sinusoids found by harmonic analysis.

in concluding that the wave was produced by a summation of vibrations in the harmonic relation. If the wave originated from a single source, we should certainly not be justified in drawing the same conclusion without further evidence. In seeking for further evidence we find, in the first place, that the waves from musical instruments so far as yet studied—the material is extremely limited—do not give harmonic plots like that in Fig. 5, and do give plots having one, two, or three prominent harmonics with the others lacking. This would agree with the known fact that most musical instruments vibrate in harmonics. If the source of the wave were absolutely unknown, the most plausible deduction would be that it was some body or bodies that might vibrate in either harmonics or inharmonics. We should take the weighted means of the groups of strong harmonics, and should find in this case that the components were the inharmonics

$$1 : 4{\cdot}3 : 9{\cdot}3 : 11{\cdot}5 : 17{\cdot}6 : 19{\cdot}5.$$

The result can be expressed in the inharmonic plot in Fig. 6. This conclusion is of vital importance, because such results are just those that are always obtained from careful vowel analyses. The very harmonic analysis itself leads to the conclusion that the vowel tones may be inharmonic.

In the analyses of vowel waves the fundamental is indicated as weak (as in Fig. 5) or often almost lacking. This fundamental represents the voice tone or the tone from the larynx. We all know that this is the strongest tone of all. We may not be able to hear just what vowel a speaker or singer is producing, but we certainly know whether he is using a high or a low tone of voice. One writer, observing this peculiarity in the analysis of the waves obtained from a phonograph, remarked that this instrument must be deaf to the voice tone. He failed to consider that if it was deaf to this tone it could not reproduce it, and that even the most defective phonograph will produce the voice tone so long as it makes any noise at all. The weakness of the fundamental in Fig. 5, therefore, does not show that

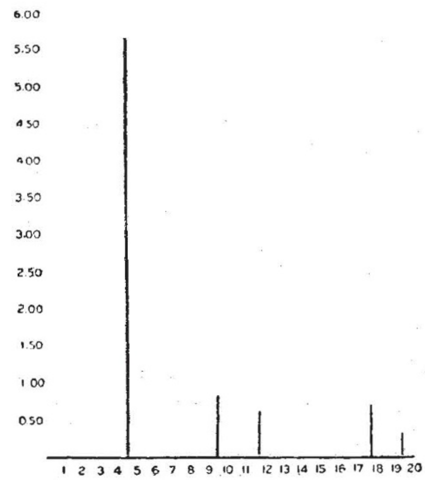

FIG. 6.—Relative amplitudes of the component inharmonics as deduced from Fig. 5.

the fundamental was lacking in the original vibration.

Let us inquire what kind of a strong tone will appear in the harmonic analysis with a weak fundamental. This is the case with a series of sharp puffs. If the period from one puff to the next of a series is subjected to harmonic analysis, the result shows a weak fundamental with all the higher harmonics represented in ever-diminishing amplitudes. The fundamentals in the vowel curves are therefore not of the nature of sine vibrations, but of series of more or less sharp puffs.

This is not a new theory of the vowels. In 1830 Willis published, in the Transactions of the Cambridge Philosophical Society, a paper on the tones of the vowels and reed organ-pipes. He asserted that a vowel was composed of a series of puffs with a set of inharmonic overtones. This was rejected in favour of the harmonic theory by Wheatstone, whose conclusions were accepted and developed by Helmholtz. For nearly a century the harmonic theory has been universally accepted.

In a series of researches beginning in 1889 Hermann found that the analyses of phonograph curves showed the vowels to be constructed of puffs and inharmonics. He thus independently rediscovered the principle of Willis. This theory has been substantiated and developed by thousands of analyses in my work for the Carnegie Institution of Washington, and published in "The Study of Speech Curves" (Carnegie Inst. Publ. No. 44), from which the above results are taken. It should be added that this extensive and somewhat expensive work was made possible by the support of Yale University and the liberality of the Carnegie Institution of Washington.

(To be continued.)

Nitrate Supplies and the Nitrogen Industry.

THE Imperial Mineral Resources Bureau has recently issued a report on the nitrate industry of the British Empire and of foreign countries, containing all available statistics with regard to the production and prices of nitrates during the war period. In conjunction with this report may be considered a paper dealing with the nitrogen industry contributed by H. E. Fischer to the Journal of the Franklin Institute (August, 1920, vol. cxc., No. 2). This paper gives a comprehensive survey of the sources of the world's nitrogen supply, particularly as it affects America. Nitrogenous compounds are absolutely necessary to agriculture, to the manufacture of munitions, to refrigeration, and to the general applications of chemistry, and although nitrogen in its inert gaseous state forms four-fifths of the atmosphere, yet this is of no use for the above objects until it has been combined or "fixed" by some method.

In the combined form, nitrogen is found in Nature as mineral deposits, as organic compounds, and in carboniferous deposits. By far the most important of the mineral deposits are those of Chile. Before the war the greater part of the world's requirements in respect of nitrate and nitric nitrogen was met by the export of nitrate of soda from Chile. The Chilean nitrate industry is one of long standing, and expanded steadily from 100,000 tons per annum in the middle of the nineteenth century to 2,400,000 tons in 1913. It has been stated that the Chilean nitrate deposits are nearly exhausted, but according to the Chilean Nitrate Committee's report "there is no fear of the Chilean nitrate deposits being exhausted for 200 years." The nitrate occurs as scattered deposits in a formation known as caliche, consisting of a conglomerate of rock material cemented with a mixture of soluble salts, in which sodium chloride is the chief constituent as regards quantity, while sodium nitrate is second. It is only in scattered patches that the caliche contains nitrate in quantities large enough to warrant treatment. These patches are sought out and excavated, and the picked ore is hauled to the extraction plant, where the soluble salts are extracted in solution, and the nitrate is separated from the other salts by crystallisation.

A considerable amount of sodium nitrate is also produced in Egypt. For one company in 1913 the output was 4740 metric tons, but the total output is not known definitely. In India potassium nitrate has been produced from very early times, but the trade has always been subject to great fluctuations. It attained its highest values during the American Civil War, for then India had practically a monopoly of the supplies of saltpetre needed for explosives. At that time the average annual exports were 30,000 tons, but the development of the Chilean industry caused the Indian trade to decline, until in the years just before the war the exports were only 13,000 or 14,000 tons per annum. The war period again stimulated the trade, and in 1918 the output was 25,145 metric tons. The potassium nitrate is found in the soils of old villages, mixed with nitrates of calcium and magnesium and with sodium chloride. The process of extraction consists in dissolving out the mixed salts from the surface soil, roughly separating the sodium chloride and the potassium nitrate, and then purifying the nitrate.

Nitrogen compounds are also obtained as by-products in a large number of industries. In dealing with animal, vegetable, and fish products, organic ammoniates are obtained, and these are left as such for use in agriculture, while from sources such as coal distillations, bone carbonisation, oil-shale distillation, and blast-furnace operations, nitrogen is recovered as ammonia and ammonium salts—chiefly ammonium sulphate, which is available in all capacities. The organic nitrogen recovered in these various by-product connections probably constitutes about 40 to 50 per cent. of the total supply, but this nitrogen has to compete for its market against the supplies of nitrates from natural sources and against those of synthetic nitrates, *i.e.* those obtained from combined atmospheric nitrogen.

As early as 1781 Cavendish discovered that a nitric reaction was shown by water obtained by burning hydrogen in excess of air, and since his time very many chemists have studied the problem. In 1900 two Americans erected an experimental plant at Niagara for producing nitric acid from atmospheric nitrogen by means of a very high electric current, but this soon proved unremunerative and was abandoned. The luminous arc process for fixing atmospheric nitrogen was the first to be established commercially. In this process a dilute gaseous mixture of nitric oxides with air is obtained from the oxygen and nitrogen in the air; the nitric oxide is converted into nitric dioxide, and then absorbed in water to form nitric acid. It was started in Norway in 1903, and, owing to the cheap horse-power there avail-