EXPERIMENTAL PHONETICS.[1]

THE movements of the organs of voice and speech are so complicated as to require for their elucidation the application of many methods of research. When one speaks there are movements of the lips, tongue, soft palate and larynx, and sometimes movements of the muscles of expression. Then, again, there are special characteristics about vowel sounds which apparently distinguish these from the sounds of musical instruments. Thus questions arise as to the true nature of vowel-sounds and as to what is the physical constitution of a word of several syllables. It has also been suggested that language might be recorded, not by letters or syllables, but by signs or symbols which would indicate what had to be done by the vocal and articulating organs for the production of any given sound. There might thus be a physiological method of expressing speech by a series of alphabetical symbols for sounds varying in pitch, ntensity and quality. It will be seen that experimental phonetics constitutes a wide field of research, not only of great scientific interest, but also one having practical aspects not at first apparent. From the nature of the investigation, also, the problems seem to be specially suited for the application of the graphic method of research.

In 1875, an investigation was carried out by Havet and Rosapelly[2] in the laboratory of Prof. Marey in Paris, in which the pressure of the air in the nose, the movements of the lips, and the vibrations of the larynx were simultaneously recorded.

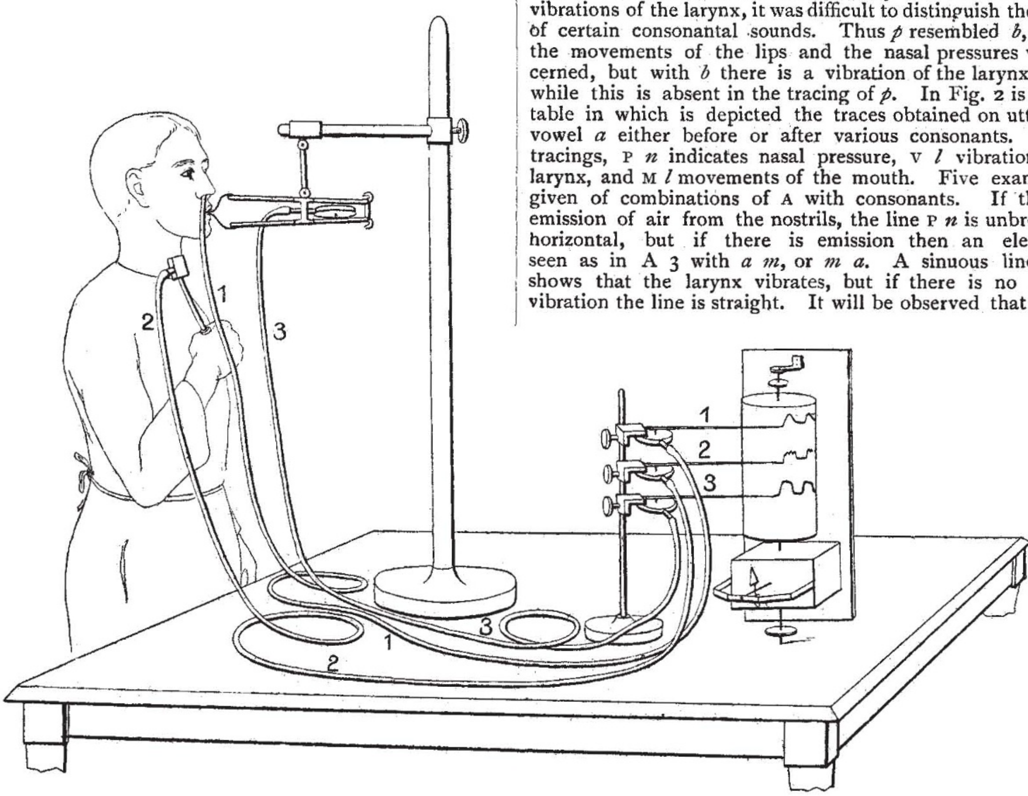


FIG. 1.—A method for recording simultaneously the different acts of speech: emission of air by the nares (tube and lever, 1) vibrations of the larynx (2), and movements of the lips (3).

Special contrivances were devised for transmitting these movements to three of Marey's tambours, so arranged as to record on the surface of a blackened drum three superposed curves which indicated the order of succession, duration and intensity of the movements of the organs. The emission of air from the nostril indicated movements of the soft palate, and these were signalled by an indiarubber tube introduced into one nostril while the other end was connected with a tambour, as in Fig. 1. A small electromagnetic apparatus was placed over the larynx, and by making and breaking a current the vibrations of the larynx were transmitted to another tambour. The movements of the lips were recorded by a device which caused the pressures to act on a third tambour, as is shown in the figure.

This method was found to give characteristic tracings for the sounds of consonants, but the records obtained from vowel-sounds were all very much alike. It was also observed that if one of the tambours did not act, say the one recording the vibrations of the larynx, it was difficult to distinguish the tracings of certain consonantal sounds. Thus *p* resembled *b*, so far as the movements of the lips and the nasal pressures were concerned, but with *b* there is a vibration of the larynx as well, while this is absent in the tracing of *p*. In Fig. 2 is shown a table in which is depicted the traces obtained on uttering the vowel *a* either before or after various consonants. In these tracings, P *n* indicates nasal pressure, V *l* vibrations of the larynx, and M *l* movements of the mouth. Five examples are given of combinations of A with consonants. If there is no emission of air from the nostrils, the line P *n* is unbroken and horizontal, but if there is emission then an elevation is seen as in A 3 with *a m*, or *m a*. A sinuous line in V. *l* shows that the larynx vibrates, but if there is no laryngeal vibration the line is straight. It will be observed that in some cases the larynx vibrates throughout all the experiment, as in A 2, while in others there is an interruption, as in B 1. The movements of the lips in M *l* show a curve which varies in amplitude and duration according as the lips are more or less approximated and according to the duration of complete or partial occlusion.

These syllabic sounds may be termed *phones*. This research is an excellent example of the application of the graphic method to the movements of speech. The method has been much developed by Rousselot[1] in the Collège de France, where there now exists a special laboratory for research in phonetics.

Prof. Marey, whose earlier researches are well known to have had much to do with the development of the kinematograph, employed, so long ago as 1888, chronophotography to catch those evanescent changes of the countenance, the sum total of which give expression to the face in speech. In Fig. 3 are seen the changes of expression in a woman's face in speaking, during a period of half a second. If these successive pictures are projected by a lantern (Fig. 4) there is an animated face on the screen. In this way Marichelle succeeds in placing before the

[1] By Prof. John G. M'Kendrick, F.R.S. Read before the Section of Physiology at the meeting of the British Association in Glasgow, September 13. "Die Phonetische Literatur von 1876–1895." By Hermann Breymann (Leipzig, 1897); "The Articulation of Speech Sounds by Analphabetic Symbols." By Otto Jespersen (Marburg, 1889): "L'Inscription des Phénomènes Phonétique." By M. J. Marey (*Revue Générale des Sciences*, 15 et 30 Juin, 1898); "Studies from the Yale Psychological Laboratory." By E. W. Scripture (1899); "Théorie de la Formation des Voyelles." By Marage (Paris, prix Barbier, 1900); "La Parole d'après le Tracé du Phonographe." By H. Marichelle (Paris, 1897); "On Vowel Sounds." By J. G. M'Kendrick and A. A. Gray, Schäfer's "Text-Book of Physiology," vol. ii. p. 1206, in which the recent bibliography is given in detail.

[2] Rosapelly: "Inscription des Movements Phonétiques," in "Travaux de Laboratoire de M. Marey" (Paris, 1875).

[1] Rousselot: "Principes de Phonétique Expérimentale" (Paris, 1897).

eyes of deaf mutes images of the movements of speech which they are urged to imitate.

It is interesting, in the next place, to trace the efforts that have been made by physicists and physiologists to record the pressures produced by sound waves and more especially those of the voice. In 1858, Leon Scott invented the phonautograph, seen in Fig. 5. In its first form this instrument gave very imperfect tracings, but it is of great interest as being the forerunner of the phonograph. It was much improved by Rudolph König, of Paris. Donders,[1] in 1868, was the first to use the instrument in the investigation of vowel-tone. Then came the logograph of Barlow[2] in 1876, which was a membrane furnished with a rigid but light lever having its fulcrum at the edge of the membrane while the power was applied from the centre of the membrane. This gave more accurate tracings, that is to say, tracings that indicated with more precision the variations of pressure on the membrane. Examples are given in Figs. 6, 7, and 8.

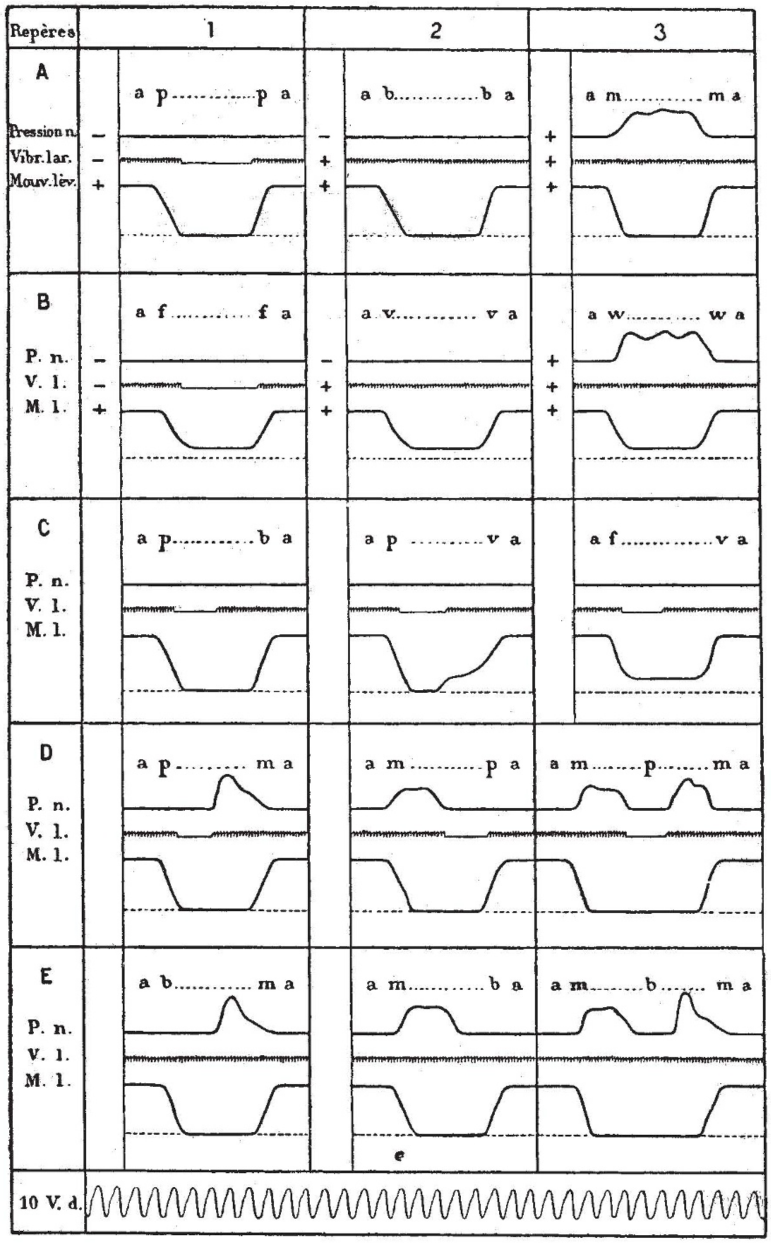


FIG. 2.—Tracings of nasal, laryngeal and labial movements in the pronunciation of various phones.

In Fig. 6 at A the membrane is at rest; at B the lever is raised by the sudden emission of the consonant *b*, and this is succeeded by the prolonged vibration of the vowel *e*. Fig. 7 gives a different picture for *e b*; A is the vowel *e*; B the closure of the lips at the beginning of the consonant; this closure lasts during C, and D is due to the elasticity of the air compressed in the mouth. In Fig. 8, *b e b*, we find the elements of Figs. 6 and 7. By the logograph the consonantal sounds were alone depicted, the records of the vowels being very imperfect.

There was still a demand for a recorder of greater accuracy. Schneebeli,[1] in 1878, devised an instrument seen in Fig. 9. From the centre of a parchment membrane arises a thin but rigid steel plate; attached to this, near the point, is another steel plate passing horizontally from the edge of the metallic ring carrying the membrane. The movements of the membrane are five times increased in amplitude, while the extreme lightness of the lever reduces to a minimum the effects due to inertia. Examples of curves obtained by this method are shown in Fig. 10.

A very sensitive apparatus, termed the *Sprachzeichner*, has also been introduced by Hensen[2] for recording the delicate vibrations of a membrane. It will be readily understood by referring to Figs. 11, 12 and 13. Valuable observations have been made with the aid of this instrument by Wendeler,[3] on consonant sounds, by Martens,[4] on vowels and diphthongs, and by Pipping,[5] on vowels.

Such are some of the mechanical contrivances that have been devised for recording the movements of a membrane. None are free from error, however delicate they may seem to be, owing to the inertia of the parts, and consequently other arrangements were demanded. In 1862[6] Rudolph König introduced his well-known method of showing the movements of membranes by manometric flames. The apparatus is now so well known as to require no detailed description. Gas is led by a tube into a small capsule of wood, the cavity of which is divided by a thin membrane (Fig. 14, A). The gas passes into the right half of the cavity and escapes into a small burner, where it is lit. If sound waves are diverted by a small conical resonator into the left half of the capsule the membranous partition vibrates, there are alternations of compression and of rarefaction in the gas on the right side, and the flame is agitated, moving upwards and downwards with each vibration. The method of Wheatstone of dissociating the flames by a rotating mirror is then employed, and a sinuous ribbon is seen in the mirror. The ribbon is cut vertically into teeth, some larger, some smaller. The larger, less frequent, correspond to the

[1] Donders: "Zur Klangfarbe der Vocale" (*Ann. der Physik und Chemie*, 1868).

[2] Barlow: "On the Articulation of the Human Voice, as Illustrate by the Logograph" (*Trans.* Roy. Soc. 1876).

[1] Société des Sciences Naturelles de Neuchâtel, 25 Avril et 20 Novembre, 1878.

[2] Hensen: "Ueber der Schrift von Schallbewegungen" (*Zeits. für Biologie*, 1887).

[3] Wendeler: "Ein Versuch über die Schallbewegungen einiger Konsonanten" (*Zeits. für Biologie*, 1886).

[4] Martens: "Ueber des Verhalten von Vocalen und Diphtongen in Zesprochenen Worten" (*Zeits. für Biologie*, 1889).

[5] Pipping: "Zur Klangfarbe der Gesungen Vocale" (*Zeits. für Biologie*, 1890); "Ueber die Theorie der Vocale" (*Arta Societatis Scientiarum Helsingfors*, 1894).

[6] König: "Quelques Experiences d'Acoustique (Paris, 1882).

fundamental tone of the sound, the smaller to the harmonics that enter into the composition of the compound tone on which the quality of the vowel depends.

These flame pictures are only seen for an instant, and many efforts have been made to fix them by photographic methods. Marage,[1] to whose researches we shall afterwards refer, feeds the capsule with acetylene, and thus obtains a luminous flame. The result of such an arrangement is shown in Fig. 17.

It will be observed that all manometric flames seen in a rotating mirror are inclined, as their composition is due to a hori-

FIG. 3.—Changes of expression during speech. Chronophotography. Ten images per second.

This was first attempted by Gerhardt [1] in 1877. He used the flame of cyanogen, and the somewhat poor result is shown in Fig. 16.

Doumer [2] obtained a brilliant flame by burning carburetted hydrogen in oxygen, and he also introduced into such re-

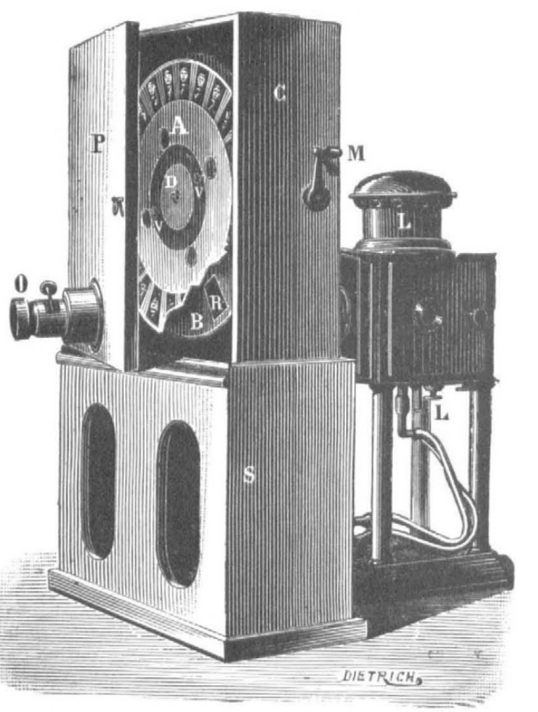


FIG. 4.—Photophone of Demeny. A, glass disc carrying the pictures; B, another disc, perforated; L, electric lamp; O, lens.

searches a chronophotographic method by reproducing the images of a flame acted on by a tuning-fork of known pitch.

[1] Stein: "Die Licht im Dienste wissenschaftlicher Forschung" (Leipsig, 1877).
[2] Doumer: *C.R.* de l'Académie des Sciences, 1886.

zontal and vertical translation, and the faster the mirror is rotated the more they are inclined.

Efforts have also been made to analyse sounds by photographing a ray of light reflected from a vibrating mirror. Long ago, but without photography, Czermak applied this method to the phenomenon of the pulse, and in 1879 Blake [2] devised a mirror for thus recording speech. He used a small metallic plate, in the centre of which was a small hook which is attached to a very light mirror delicately swung on two pivots, *c*, *c*, Fig. 18.

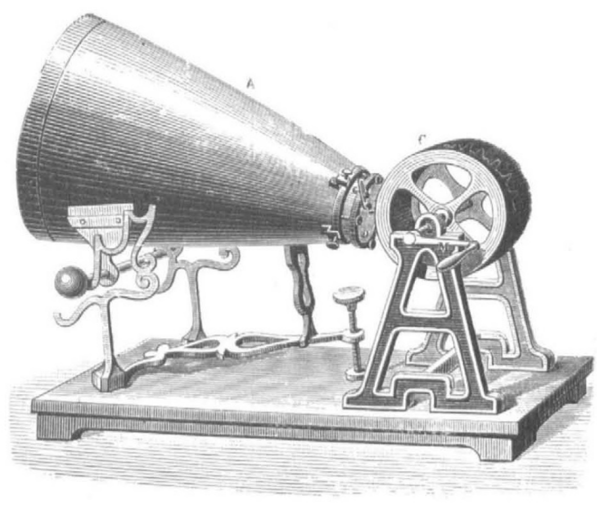


FIG. 5.—Phonautograph of Leon Scott. A paraboloid resonator, closed at one end by a membrane, to which a light lever is attached. C is a drum covered with smoked paper on which the lever traces a curve. As C rotates, it moves from right to left.

A ray of light is thrown on the mirror by a convex lens; after reflection it again traverses a lens and falls on a photographic plate in movement. Sharp, well-defined images are thus obtained (Fig. 19).

[1] Marage: "Étude des Cornet Acoustiques par la Photographie des Flammes Manometriques de König" (1897).
[2] Blake: *American Journal of Science and Art*, 1878; *Journal de Physique*, 1879.

The amplitudes of the tracings thus obtained from the tones of the voice were $0^{m}, 025$ (1 inch), while those of the mirror were only $0^{mm}, 125$ (1/200th inch).

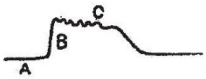


FIG. 6.—Tracings of the sound *b e*.

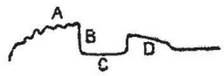


FIG. 7.—The sound *e b*.

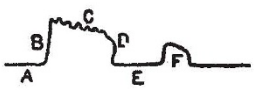


FIG. 8.—The sound *b e b*.

Rigollot and Chavanon,[1] in 1883, constructed a mirror-apparatus shown in Fig. 20, and Hermann,[2] in 1889, used a somewhat similar arrangement, the tracings of which are given in Fig. 21.

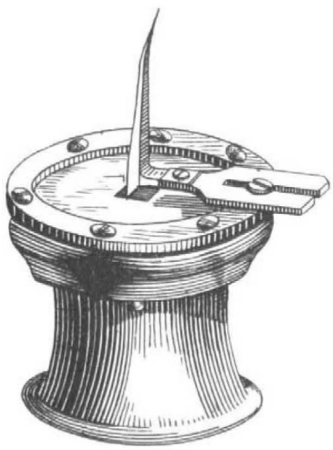


FIG. 9.—Arrangement of Schneebeli for recording movements of a membrane.

An ideal method for recording vibrations was devised by Rops in 1893, ideal inasmuch as it does not use any vibrating membrane or lever, or anything having inertia. A diagram is given in Fig. 22.

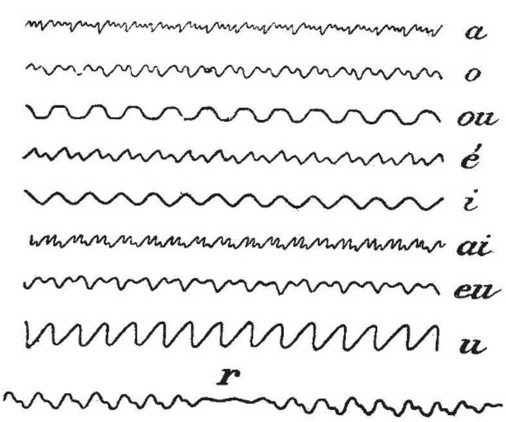


FIG. 10.—Curves of various vowels and of the consonant *r* recorded by the apparatus of Schneebeli.

It is based on the principle of photographing the effects of interferences of light waves. Rays from a luminous source A pass through the lenses *q q* so as to become parallel. They then pass through a slit *d* and a hole in a diaphragm *b*, and they are focussed by a lens *l* (of 15 centimetres focal length) so as to fall on a glass plate S_1. The ray divides into two, a_1 and a_2, and they run parallel, the ray a_1 passing through the air while a_2 passes along a tube *g* (15 centimetres in length), the ends of which are closed by the glass plates *h* and h_1. A few centimetres from the tube there is a resonator, *i*, into which the vowels are sung, thus causing condensations and rarefactions of the air,

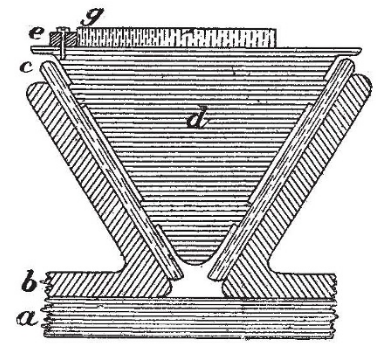


FIG. 11.—Apparatus of Hensen. *d*, Wooden prism; *c*, glass; *g*, smoked glass kept in its place by a screw clamp, *e*; *a*, *b*, supports.

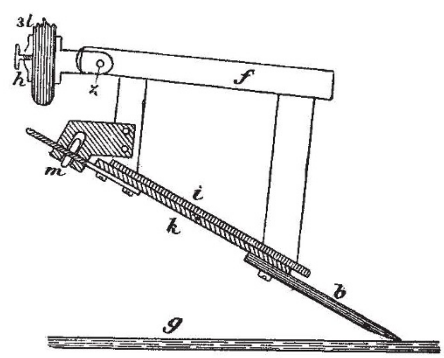


FIG. 12.—The recording portion of the Sprachzeichner of Hensen. *f*, *i*, frame having a joint, *z*; *b*, wooden point; *g*, smoked glass.

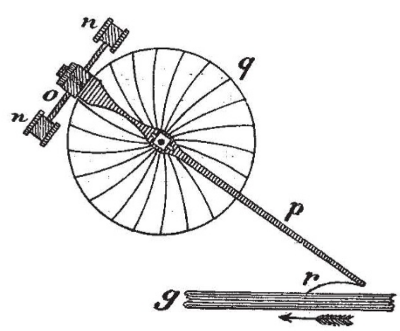


FIG. 13.—Writing portion of Hensen's apparatus. *n*, *n*, weights supporting an axis *o*, carrying marker *p*, with a point *r*; *q*, a disc communicating to the marker *p* the movements of the membrane; *g*, smoked glass plate.

disturbing the ray *h* h_1, while the ray passing through the tube *g* is unaffected. The two rays are again united by S_1; they then pass through an objective *c* and a lens *z* to a slit in a screen so as to fall on sensitive paper on the drum T. A diaphragm *b* cuts off secondary reflections. Thus beautiful images are formed corresponding to the vowels spoken or chanted into the resonator.

The invention of the tinfoil phonograph by Edison in 1877, and the improvement of the instrument by the labours of Edison,

1 *Journal de Physique*, 1883.
2 Hermann: *Pflüger's Archiv*, 1889.

Graham Bell and others in more recent years, has made it possible to investigate phonetic phenomena with the aid of this instrument. In 1878 Fleeming Jenkin and Ewing[1] devised a method of recording curves from the imprints on the tinfoil covering the drum of the phonograph, and these curves were submitted to harmonic analysis. This was also attempted by A. M. Mayer[2] in the same year. The subject was taken up by Hermann[3] about 1890, and he obtained valuable tracings by using the wax-cylinder phonograph. He succeeded in obtaining photographs of the curves on the wax cylinder, a beam of light reflected from a small mirror attached to the vibrating disc of the phonograph being allowed to fall on a sensitive plate while the phonograph was slowly travelling. In 1891 Boeke[4] measured with great accuracy the dimensions of the marks on the wax cylinder, and from these constructed the corresponding curves. This method has also been adopted by Marichelle.[5] McKendrick,[6] in 1895, photographed the marks on the wax cylinder of the phonograph, and in 1896 he devised a recorder for enlarging the curves on the well-known principle of the syphon recorder. In 1899 Scripture,[7] of Yale, investigated vowel-sounds with the aid of the gramophone. He transcribed, by an ingenious mechanical device, the marks on the gramophone disc into the forms of curves, and made a minute analysis. Lastly, Marage,[8] in a series of masterly papers, reinvestigated

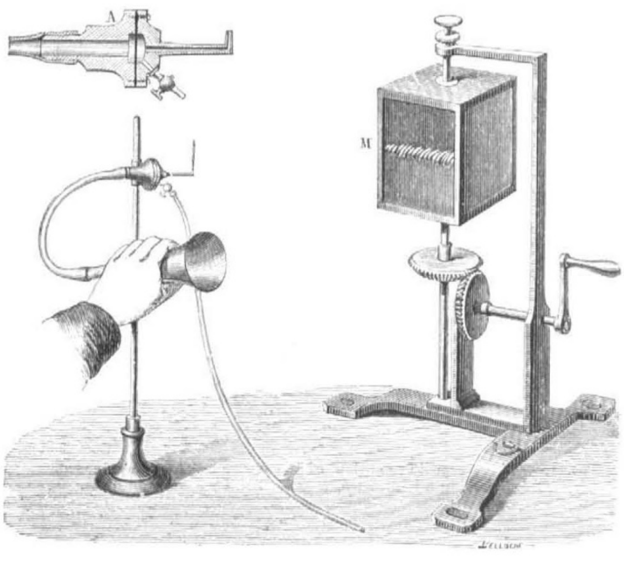


FIG. 14.—König's apparatus. A, Manometric capsule; M, rotating mirror.

the whole subject of vowel-tones with the aid of a chronophotographic method and a special form of syren invented by himself.

The various experimental methods we have described have been chiefly directed to an examination of the nature of vowel-sounds. What is it that gives the peculiar quality to the sound of a vowel? How is it that we can, by the ear, identify the sound of any vowel, whether it be spoken or sung? How is it that if we sing a vowel on the notes of a scale we can still identify the vowel, whatever may be the pitch of the note on which it is sung? The scientific investigation of the nature of vowels begins with Willis,[1] who, in 1829, imitated the larynx by means of a reed, above which he placed a resonator, tuned to one of the harmonics of the reed. He also imitated vowel-tones by holding an elastic spring against the edge of a toothed wheel, and he placed the vowels in the following order—*ou*, *o*, *a*, *e* and *i*. In each case a compound tone was produced which retained the same pitch so long as the wheel revolved at the same rate. By keeping the wheel revolving at a uniform rate, and at the same time changing the length of the spring which was allowed to vibrate, Willis found that the qualities of various vowels were imitated with considerable distinctness. In 1837 Wheatstone,[2] in a criticism of Willis, made some important suggestions. In 1854 Grassmann[3] announced a theory as follows:—The vocal cords excite the resonances of the cavity of the mouth; the tonality changes with the degree of opening of the mouth by the development of some of the harmonics of the fundamental tone emitted by the larynx. According to this view, the buccal cavity adds by its resonance certain harmonics to the fundamental laryngeal sound. Grassmann classified

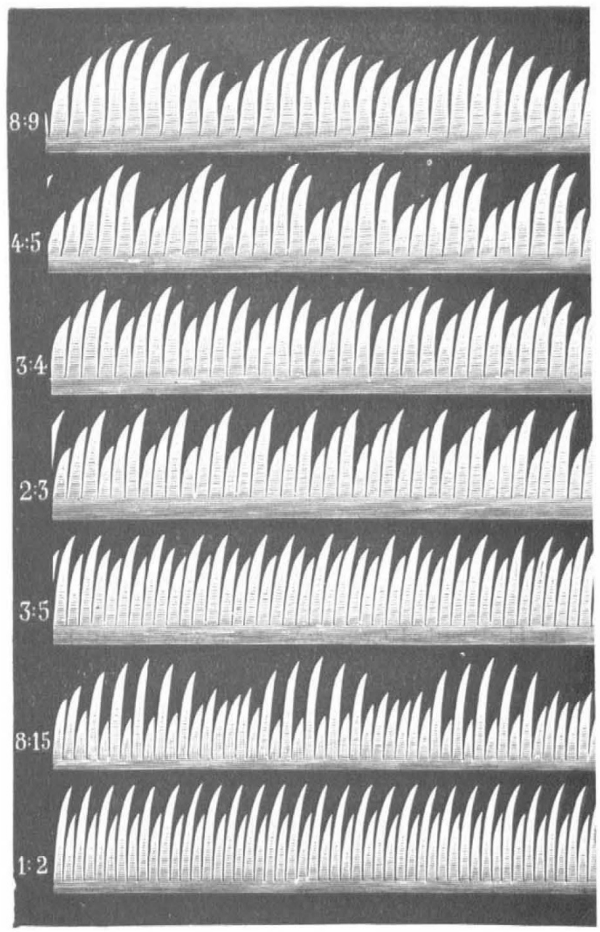
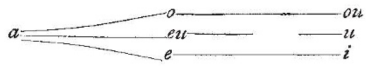


FIG. 15.—Examples of flame-pictures obtained by König's system of a manometric capsule adapted to two organ pipes. The figures to the left indicate the ratio of the vibrations of the two tones forming the compound tone.

1 Fleeming Jenkin and Ewing: "On the Harmonic Analysis of certain Vowel Sounds" (*Trans.* Roy. Soc. Edin., vol. xxviii. p. 745).
2 Mayer: *Journal de Physique*, 1878.
3 A full bibliographical reference to Hermann's papers is given in Schäfer's "Text-Book of Physiology," vol. ii. p. 1222.
4 Boeke: "Microscopische Phonogrammstudien" (*Archiv* f. d. ges. Physiol., Bonn, Bd. i. S. 297; also *Proc.* Roy. Soc. Edin., 1898.)
5 Marichelle: "La Parole d'après le Tracé du Phonographe" (1897).
6 McKendrick: *Trans.* Roy. Soc. Edin., vol. xxxviii. pt. iv.; *Proc.* Roy. Soc. Edin., 1896–97; also "Sound-Waves as Revealed by the Phonograph" (London, 1897.)
7 Scripture: "Studies from the Yale Psychological Laboratory" (1899.)
8 Marage: "Comment parlent les Phonographes"; "Les Exercises Acoustiques chez Les Sourds-Muets"; "Rôle de la chaîne des osselets dans l'Audition"; and "Théorie de la Formation des Voyelles" (from 1897 onwards).

1 Willis: Cambridge *Phil. Trans.*, 1829, vol. iii. p. 231: also *Ann. d. Phys. u. chem.*, Leipsig, Bd. xxiv. p. 397.
2 Wheatstone, *Westminster Review*, October 1837.
3 Grassmann, "Über die physik. Natur der Sprachleute," 1877; he had, however, in 1854, enunciated his theory in "Uebersicht der Akustik u. der niedem Optik."

the vowels according to the number of harmonics which they contained, in the following table :—



In sounding *a* the mouth is widely opened and the fundamental and eight harmonics are produced; in the third series, on the contrary, there is only one harmonic sounded, which is more and more acute as we pronounce the vowels in the order *ou*, *u* and *i*. The vowels of the second series, *o*, *eu* and *e*, are transitional between the first and the third. Thus we pass from *a* to *ou* by *o*, from *a* to *u* by *eu*, and from *a* to *i* by *e*.

Donders[1] showed that the cavity of the mouth, as arranged for the giving forth of a vowel, was tuned as a resonator for a tone of a certain pitch, and that different pitches coresponded

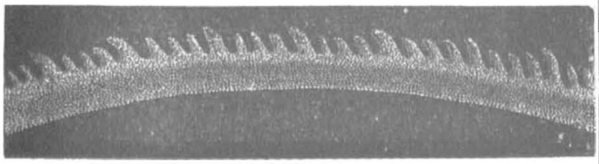


FIG. 16.—Vibrating flame of cyanogen photographed by Gerhardt.

to the forms of the cavity for the different vowels. This he discovered by the peculiar noise produced in the mouth when the different vowels are whispered. The cavity of the mouth is then blown like an organ-pipe and by its resonance reinforces the corresponding partials in the rushing wind-like noise. Then the question was taken up by Helmholtz.[2] He attacked it both by analysis and by synthesis. He analysed the vowel-tones by his well-known resonators, aided by his own singularly acute ear, and he attempted to combine, by means of tuning-forks, the tones which he thought existed in a vowel, so as to reproduce the sound of the vowel. In the latter part of the investigation he was by no means successful. These investigations led Helmholtz to put forward in succession two theories as to the formation of vowels. The first was that, as in all musical instruments, the quality or timbre of the vowel depends on the fundamental tone, reinforced by certain partials or overtones, of which a number are produced by the vocal cords along with the fundamental tone, the reinforcement depending on the resonance of the cavities above the vocal cords. This theory was upset by the use of the phonograph. If a vowel is sung to the phonograph while the cylinder is travelling at a certain speed, the vowel-tone will be reproduced with exactly the same quality if the cylinder is driven at the same speed, but if it is driven faster, then the quality of the vowel will be changed, so much so as to be scarcely recognisable. M. Marey narrates that Donders and he first made this observation when it so happened that the two savants were present in Paris at a public demonstration of the phonograph soon after its invention. Donders sang the vowel tones to the instrument, and then asked the operator to vary the speed of the cylinder during reproduction. Then the vowel *a* became *o*, and *e* became *ou*. Thus while the phonograph reproduces in a wonderful way the tones of musical instruments without change of quality, it cannot transpose vowel-tones without altering their character. This special character or quality cannot, then, depend on the overtones reinforced by the oral cavities being simple multiples of the fundamental tone, and Helmholtz's first theory had to be abandoned.

This led Helmholtz to advance a second theory as follows :—Each vowel is characterised by a certain harmonic or partial tone, of constant pitch, whatever may be the pitch of the note on which the vowel is sung or spoken. Attempts were then made, notably by Helmholtz and König, to fix the pitch of the characteristic partial tone or vocable, and there appeared to be

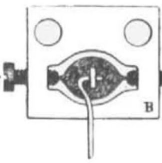


FIG. 18.—Blake's mirror

considerable differences in the results of the two distinguished observers, differences amounting to as much, in some cases, as three semi-tones.

The next step was, as has already been explained, to transcribe the marks on the wax cylinder of the phonograph, made on singing or speaking a vowel, into sinuous curves and to subject these to harmonic analysis. It is not difficult, in comparatively simple cases, to obtain a curve which is the algebraic sum of the ordinates of several sinussoidal curves, but it is not so easy to do the reverse operation, namely, to analyse the curves. Fleeming Jenkin and Ewing, afterwards Schneebeli, Hensen, Pipping and Hermann, have done this in accordance with the theorem of Fourier and the law of Ohm. In particular, Hermann, by a beautiful and ingenious method, has analysed the curves obtained by his photographic device, and has modified the theory of Helmholtz. His statement is that the oral cavity produces independently a harmonic or partial tone which has no definite relation to the fundamental tone emitted by the larynx. A vowel, according to him, is a special acoustic phenomenon, depending on the intermittent production of a special partial, or "formant," or "characteristique." The pitch of the "formant" may vary a little without altering the character of the vowel. For *a*, for example, the "formant" may vary from fa_4 to la_4, even in the same person. He has also attempted, but not with complete success, to reproduce the vowel-tones by synthesis.

There are thus three theories: (1) the first of Helmholtz, now abandoned, that the pitch of the partials is represented by simple multiples of the vibration periods of the fundamental; (2) the second of Helmholtz, that the pitch of the characteristic partial is always fixed, but has a definite relation to the pitch of the fundamental; and (3) that of Hermann, that the pitch

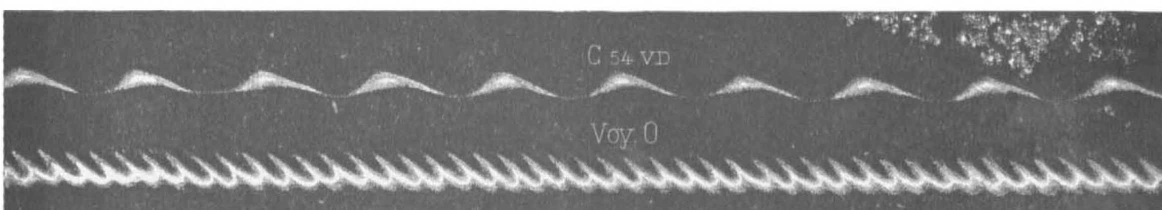


FIG. 17.—Photograph of manometric flames of acetylene showing vibrations of vowel o. Above are the images of chronographic flames—54 double vibrations per second.

1 Donders: "De physiologie der Spraakklanken" (1870).

2 Helmholtz: "Ueber de Vokale." *Archiv*. f. d. Holland. Beitr. 2, Nat. u. Heilk. (Utrecht, 1857). See other references given in Schäfer's "Text-Book," vol. ii. p. 1217 (footnote).

of the characteristic partial or "formant" is not absolutely fixed.

The difficulty of harmonising these theories has stimulated the zeal of many workers, and in particular Dr. Marage[1] has been remarkably successful in his researches into the nature of vowels. He first of all criticises the second theory of Helmholtz, pointing out that the failure to reproduce the vowels by synthesis is strongly against it. Thus while, by tuning-forks, the pitch of which is that of the partials of the fundamental tone, *ou*, *o* and *a* may be badly reproduced, it has been found impossible to reproduce E and I. He then objects to the theory of Hermann, namely, that the vowel is an oral intermittent and oscillating tone; first, that the method of recording the vowel on the wax cylinder of the phonograph causes grave errors, because the mouthpiece, tube, air chamber and vibrating disc all profoundly modify the vowel; second, that the method of analysis by Fourier's theorem assumes that the vowel curves are constituted by superposed simple curves, which is precisely the question at issue, and therefore the argument is a *petitio principii*; and third, that the data obtained by his method have

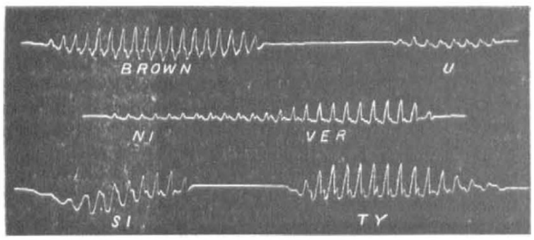


FIG. 19.—Photographic tracings obtained by Blake's method.

not enabled Hermann to reconstruct the vowels with greater success than Helmholtz. Marage then enters upon his own method, which consists essentially of using a special apparatus constructed on König's principle of manometric flames, but so

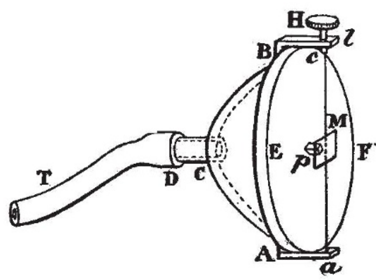


FIG. 20.—Palmoptic capsule of Rigollot and Chavanon (παλμικος, pertaining to vibrations). E F, collodion membrane; M, mirror carried by a wire *a c*, stretched between supports A and B, and regulated by the screw H; *p*, small cube of india-rubber resting on centre of membrane; T, tube.

simple as to be practically free from sources of error; that is to say, there is no mouthpiece, tube or lever. The pictures of the flames were produced photographically by feeding the flame with acetylene gas, and chronophotometrical records were taken with each experiment. He then finds that the flame pictures of I, U and OU show *one* flame, E, EU and O two flames, and A three flames. So that the classification of the vowels by flames is exactly that of Grassmann. Each vowel, when all errors have thus been got rid of by simplifying the apparatus, always gives the same picture for any given note. The picture is that of a continuous periodic curve, and the number of periods in a second corresponds to the laryngeal note, while the *form* of the period characterises the vowel. With the same vowel the period changes with the note. When the note is near the pitch of ordinary speech, the period varies very little. This is not so when the vowel is sung; the period then disappears until there is only the laryngeal note. Marage has also by synthesis reproduced the vowels with remarkable success. His first experiments with resonators were not quite satisfactory; he could reproduce OU, O and A, but not E and I. He ascertained, however, that to reproduce A the resonator must be tuned to the third harmonic or partial of the note on which A was sung; that to reproduce E, EU and O the best result was obtained when the resonator

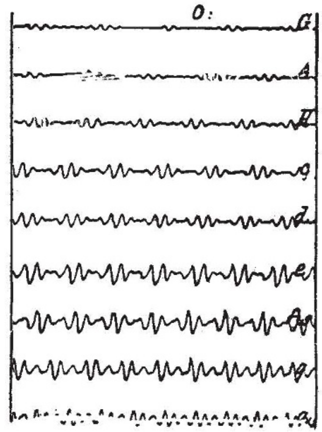


FIG. 21.—Tracings obtained by Hermann of vowel O.

gave the second partial; and I, U and OU were imitated (but not successfully) when the resonator was in unison with the laryngeal tone.

Marage finally devised a syren rotated by an electric motor and consisting of a disc having in it a triangular window representing the glottis. The air is driven under pressure through this aperture and then falls on another disc having windows cut out of it in groups according to the nature of the vowel to be synthetically reproduced. Thus the disc for A has four groups, each group consisting of three triangular slit-like windows; for O and E the disc shows five groups, each consisting of two slits; and for I and OU there are many slits, without these being arranged in groups. The slits are very large for O and narrow for E, and large for OU and narrow for I. He then moulded a series of casts of the interior of the oral and pharyngeal cavities of a human subject, as these were adapted for the singing of the different vowels, and from them constructed masks or headpieces which could be placed over the syren so that the air escaping from it passed through the cavities of the mask. He found that if air was driven through the masks under a pressure of only 7 centimetres of water, the timbre of the corresponding vowel was at once perceived, as in whispering. Marage's view is that to form a vowel the true vocal cords vibrate in a horizontal plane, in such a way as to influence by their greater or less degree of approximation the escape of air.

If the air escapes in three little puffs as it were (the cords vibrating during each puff a number of times equal to the pitch of the note on which the vowel is spoken or sung), so that

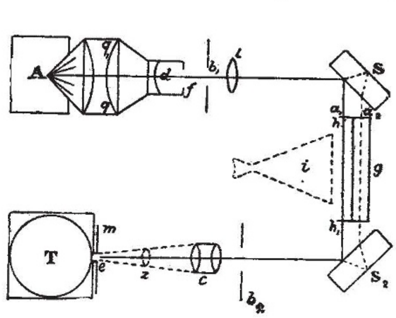


FIG. 22.—Rops' apparatus for the analysis of vowel-tones.

there are intervals between the groups of puffs, then the vowel A is the result. The oral resonator is in unison with the sum of the vibrations and the vowel is emitted. If the resonator (either artificial or the oral cavity, as in life) is turned to the

[1] Marage: "Théorie de la Formation des Voyelles," *op. cit*

third harmonic of this note, then the vowel A is modified; the same applies to E and O, which have the second harmonic, and in passing from the one vowel to the other it is sufficient to change the aperture of the glottic opening. Thus for A, if the fundamental note is n, the oral resonator must be tuned to $3n$; for E and O, if the fundamental is n', the oral resonator gives $2n'$; and for I and OU the resonator is in unison. If this is not so, then the quality of the vowel is much altered. Thus if the syren gives A, and the plate used is that for OU, then the sound is A modified. This agrees with the experience of teachers of singing, who hold that a badly sung vowel is a vowel-sound emitted into a cavity adjusted for another vowel. Marage has also found that when the sounds of his syren, aided by the masks, are examined by the manometric method, the flame pictures appear as they may be expected to do, that is, groups of three flames for A, of two for E, EU, and O, and of one for I, U and OU. Vowels then, according to him, are due to an intermittent aëro-laryngeal vibration, strengthened by the oral cavity and producing OU, O, A, E and I, when it is in unison with the sum of the vibrations; transformed by it, and giving origin to other vowels, when there is no unison; and the number of intermittences gives the fundamental note on which the vowel is emitted. If the oral cavity acts alone, the vowel is whispered; if the larynx acts alone, the vowel is sung; and if the two act the vowel is spoken. Marage has applied his method with much success in testing the ear and in the treatment of mutes who are not absolutely deaf. His memoir is characterised by great simplicity and at the same time by thoroughness.

But the study of vowels is not the only result of recent research in phonetics. The analysis of consonantal sounds is now being carried out by various workers, such as Pipping, Scripture and Lloyd. Meyer, in Hermann's laboratory, has investigated the pitch of words, sentences and syllables in speech. This has also been studied by phonographic tracings by Marichelle. The whole subject has also a practical bearing, as the knowledge acquired enables the teacher of deaf mutes so to instruct his pupils in the use of their organs as to avoid the dreary monotone of those who learn to speak by watching only the movements of the lips.

It only remains to notice the remarkable monograph of Jespersen. This is an attempt to aid the study of phonetics by the use of a scientific nomenclature to express sounds, so that just as the chemist represents by letters and figures the nature of a chemical substance of complex constitution, so the student of phonetics may be able to express the sounds of words by symbols. The visible-speech system of Melville-Bell consisted of symbols which expressed more or less accurately the physiological movements to be made, or the position to be assumed, during the pronunciation of a given sound; but the symbols of Jespersen are letters and figures. The letters or figures, however, to be useful must have a physiological meaning. Strictly speaking the symbols denote, not sounds, but the elements of sounds. Thus so simple a sound as *m* is physiologically the result of (*a*) lips shut; (*b*) point of tongue resting in the bottom of the mouth; (*c*) surface of tongue not raised towards the palate; (*d*) nasal passage open; (*e*) vocal cords vibrate; and (*f*) air expelled from lungs. The attempt of Jespersen may be called an analphabetic system of writing, symbolising, not sounds, but the elements of sounds. At present it is severely technical, but it seems to "provide a means of writing down and describing phonetic minutiæ in a comparatively easy and unambiguous manner." It will do for the phonetician what symbolism does for the mineralogist. It is a kind of algebra for speech sounds.

In advocating the establishment of a photographic museum, to be a visual register of the past, Janssen recently wrote as follows:—"Photography registers the chain of phenomena during time, just as writing registers the thoughts of men during the ages. Photography is to sight what writing is to thought. If there is any difference, it is to the advantage of photography. Writing is subject to conventionalities from which photography is free; writing employs a particular language, while photography speaks the universal language."

But if there is to be a museum of photographs, appealing to the sense of sight, why should we not have a museum of sounds, in the shape of phonograph records, appealing to the sense of hearing? How little can we tell from written characters the exact sounds of ancient Sanskrit, or how Demosthenes spoke in Greek or Cicero in Latin? Would it not now be interesting to hear the exact accent of old English, or the Scotch of the fifteenth century? All dialects should be carefully registered and put aside for future consultation, and thus we would do for the ear what we do for the eye. No doubt such a collection of phonographic records would help onwards the science of language.

THE ANCIENT GLACIERS OF SKYE.

IN the central portion of Skye there is a group of mountains unequalled elsewhere in Britain for rugged grandeur. To the south and south-west lie the Cuillin Hills, the serrated peaks of which rise to an elevation of more than 3000 feet; they are built essentially of a great laccolitic mass of gabbro, traversed by countless dykes and sheets of basalt. To the north lie the Red Hills, the smoother outlines and often ruddy aspect of which contrast markedly with the dark and rough elevations of Blath-bheinn, or Blaven, and the Cuillins; they are composed of granite and granophyre, and rise to heights rarely exceeding 2500 feet.

That the whole of this mountain district has been severely glaciated has for many years been recognised, but the detailed history of the ice-erosion has not hitherto been worked out. Mr. Alfred Harker, in the course of a special survey of the region, has had opportunities of study which have enabled him to write an essay on the subject which for completeness and lucidity is probably unsurpassed.[1] The district, as he points out, is one which had for long been subject to erosion; the drainage system in pre-Glacial times was a fully matured one, and the features then stood out in bold relief. Moreover, the amount of post-Glacial erosion has been so trifling that the effects of ice- and frost-action remain practically without modification by later agencies.

Mr. Harker tells how during the period of maximum glaciation the Skye mountains supported a true ice-cap, under which they were wholly buried, and this ice-cap was sufficiently powerful to withstand and divert northwards and southwards great portions of the ice-sheet from the Scottish mainland. He sees evidence of the movements of the lower layers of ice in the striæ on the rock-surfaces and in the dispersal of boulders; the upper layers not improbably took a course less restricted by the form of the ground. He describes the way in which the ice must have been forced into hollows and openings; its action in grinding down and tearing away rocks, irrespective of their mineralogical composition or structure; and its mode of widening and deepening valleys. Attention is drawn to the formation of cirques or corries, due consideration being given to their aspect and relation to the amount of sunshine. The erosion by ice-action of rock-basins, such as those occupied by Loch Coruisk and other lochs and tarns, is clearly stated and is one of the most effective arguments lately published on the subject.

Mr. Harker's observations lead to the conclusion that the principal glaciation was followed by a later and minor period of ice-action, when glaciers occupied the valleys, and, as would be expected, it is not always possible to discriminate between the work done by the greater and lesser agents. The movement of the later ice was, however, very different on many parts of the lower ground from that during the principal glaciation, a difference due to the withdrawal of the Scottish ice-sheet. To the later glaciation are attributed the perched blocks which occur on the bare slopes of some of the Cuillin valleys. That the higher ridges and summits of the ranges show little or no effects of glaciation is due to the fact that they acted as ice-sheds, and escaped erosion owing to the lack of rock-débris in the ice overlying them.

The mountains, as pointed out by Mr. Harker, are for the most part of bare rock, so also are the higher corries, except where encumbered with screes; while in the lower corries and main valleys the drift is never so thick as to obscure the true form of the ground. Hence the story of the ice-erosion is very plainly engraved on the land, while the author's intimate knowledge of the petrology has enabled him to track the courses of many boulders of peculiar mineral composition with absolute certainty.

[1] "Ice-Erosion in the Cuillin Hills of Skye." By Alfred Harker, M.A., F.G.S. *Trans.* Roy. Soc. Edin., vol. xl. part ii., 1901.