blickliche Anzeige der Frequenzverteilung in Breiten von 1/3 Oktave vereinigt das Tonfrequenz-Spektrometer nach Freystedt (1), dessen Schaltung Abb. 7 und dessen Aeusseres Abb. 8 zeigt. Das Gerät wurde vorzuführt und gesondert ein dazugehörigen Film über seine Wirkungsweise gezeigt.

Zusammenfassung

Objektive Lautstärkenmesser verschiedener Bauweise bilden die Eigenschaften des menschlichen Ohres zum Teil so gut nach, dass ihre Angabe mit dem Mittelwert einer grosser Zahl von subjektiven Messungen übereinstimmt. Für zeitlich stark schwankende Geräusche, insbesonders spitzenhaltige ist die objektive Anzeige systematisch viel kleiner als die subjektive. Die Lautstärke ist nur ein Teil des Schalleindruckes. Der zeitliche Verlauf und die Verteilung der Schallanteile auf die verschiedenen Frequenzen werden häufig ebenso zur Charakterisierung benötigt wie die Lautstärke. Hierfür stehen einige Geräte zur praktischen Verwendung, die kurz angegeben werden.

16. Mr. Dennis Fry (London) : *On the Behaviour of Sensitive Flames and their Application to Speech Training.*

Although the phenomenon of the sensitive jet has received a good deal of attention since the days when Lecònte and Tyndall made their first enquiry into the matter, certain points still require explanation. These, however, must be left to the physicists. The object of this paper is merely to give a short account of the general characteristics of sensitive flames, together with certain results which I have obtained in examining their response to speech sounds.

I propose to deal briefly with the conditions for sensitivity in jets, and then with their response to pure tones before considering their reaction to speech sounds (2).

The general appearance and behaviour of sensitive flames are doubtless well-known. The flames are usually lighted jets of coal gas which show a marked decrease in height when certain sounds are produced in the vicinity. The „ducking" of the flame

(1) E. Freystedt, *Zeitschr. f. techn. Physik.*, Bd. 16, S. 533, 1935.

(2) For information and help in preparing the first part of my paper, I am indebted to Dr. G. B. Brown of University College, London (see his paper „On Sensitive Flames", *Philosophical Magazine*, vol. XIII, Jan. 1932) who has also been good enough to lend two of the figures (figures 1 and 3) which are reproduced here by permission of the Editors of the *Philosophical Magazine*. I have to thank also Mr. Stephen Jones, late of University College, London, who supplied a number of the jets examined.

in a really sensitive jet is easily visible ; one flame examined, for instance, would decrease by about one half of its height at the sound of the rattling of keys.

The degree of sensitivity of a flame depends mainly on two factors (*a*) the size and shape of the jet and its orifice and (*b*) the pressure of the gas. In the present investigation the jets used included the ordinary Bunsen type of burner, the Rayleigh type and others which were plain tubes of glass or metal with a small orifice. The Rayleigh type differs from an ordinary Bunsen burner in that the sound acts upon the unlit column of gas in the stem of the burner and not directly upon the flame. At the base of the stem, the gas passes through a chamber of which one side is a diaphragm of rubber or some other substance which allows the passage of sound but protects the jet from draughts. By far the most sensitive jets were made by using a glass tube of about 5 mm. diameter. The tube was held in a Bunsen flame until one end was almost sealed and a small orifice of 1-2 mm. diameter was left. Another type of jet was made by soldering a thin sheet of metal over one end of a metal tube (from 0,5 to 1 cm. in diameter) and making a pinhole in the metal sheet.

In examining the behaviour of sensitive jets, a pressure pump is often used to provide gas at a high pressure, but in these experiments on speech sounds the normal gas supply was used and the pressure was regulated quite simply by placing a screw clip across the rubber tube which led from the gas tap to the jet. By this means, the gas pressure could be reduced to a minimum and then increased by small degrees.

If a jet is connected in this manner to the gas supply and the stream of gas issuing through the orifice is lighted, the flame burns steadily when the pressure is at the minimum. If the pressure is gradually increased, the flame lengthens and continues to burn steadily until the pressure reaches a certain critical value, when it breaks down, becomes turbulent and is much shorter than in its previous stages. The flame is sensitive to sounds at the point when it is about to become turbulent. This means that if a sound is produced near the flame while it is in this condition, the flame will „duck" and turbulence will set in which will last as long as the sound continues. The visible effect will, in fact, be similar to that of increasing the pressure still further (though the condition produced by the latter is in reality quite different).

An investigation of the response of sensitive jets to pure tones made by Dr. Brown has revealed some very interesting facts. He found that when a given jet was subjected to frequencies ranging from 0-17,000 cycles, the flame registered certain maxima and minima of height at different parts of the frequency range. Fig. 1 shows the curves for various different jets, obtained by plotting the height of the flame against the frequency range. The same figure shows also that jets vary a great deal in sensitivity, that is, in the extent of the range to which they respond.

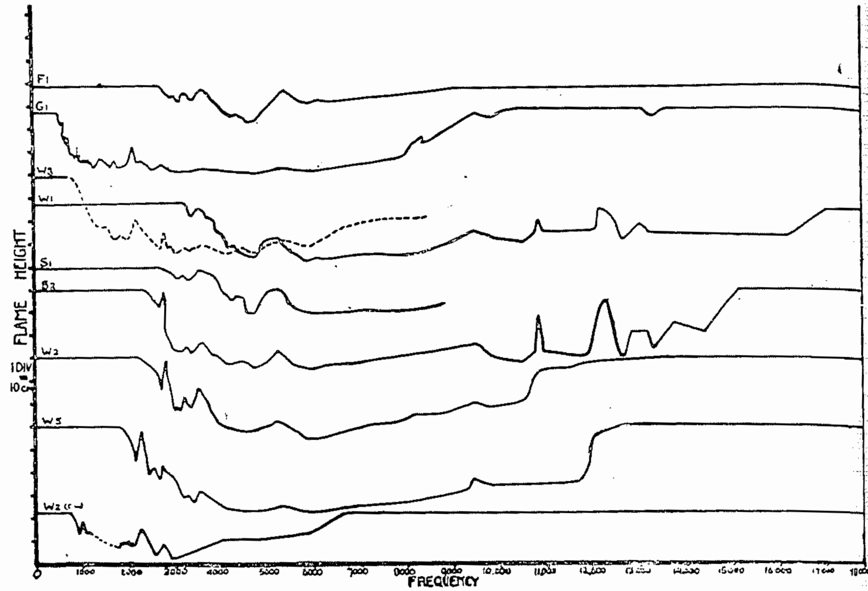

Fig. 1

Some begin to respond comparatively early in the range, and end early, others begin late and end late. We may say in general that the most sensitive flame is that which responds over the widest range of frequencies. Another striking fact, which is also illustrated in the figure, is that where several jets are sensitive over the same part of the range, they all show maxima and minima at the *same* frequencies. In other words, by varying the shape of jet, size of orifice and gas pressure we can only alter the range of frequencies to which the flame responds and not the points at which maxima and minima occur in any given range.

With regard to the response of jets of different types, it may be said, generally, that those of the Rayleigh or ordinary Bunsen type respond to a low band of frequencies (one Rayleigh jet had minima at 250, 400 and 1,200 cycles) whilst the plain glass or metal tubes answer to a much higher band (in some cases even above 17,000 cycles). It should be mentioned at this point, that the making of jets which will respond to a particular

frequency band is mainly a matter of chance since the minutest differences in the orifice of a jet or the smallest change in gas pressure will affect the range of frequencies to which it is sensitive.

Turning now to the response of the flames to complex sounds, in particular to speech sounds, it is evident that one could not expect the results to be as clear or as consistent as in the case of pure tones since in any one sound there would be a number of different frequencies to which the flame might respond. It might be reasonably supposed, however, that the most prominent characteristic frequencies of any speech sound would be the deciding factor in determining the response of a flame. Accordingly a table of English speech sounds was drawn up in which the sounds were arranged so that their characteristic

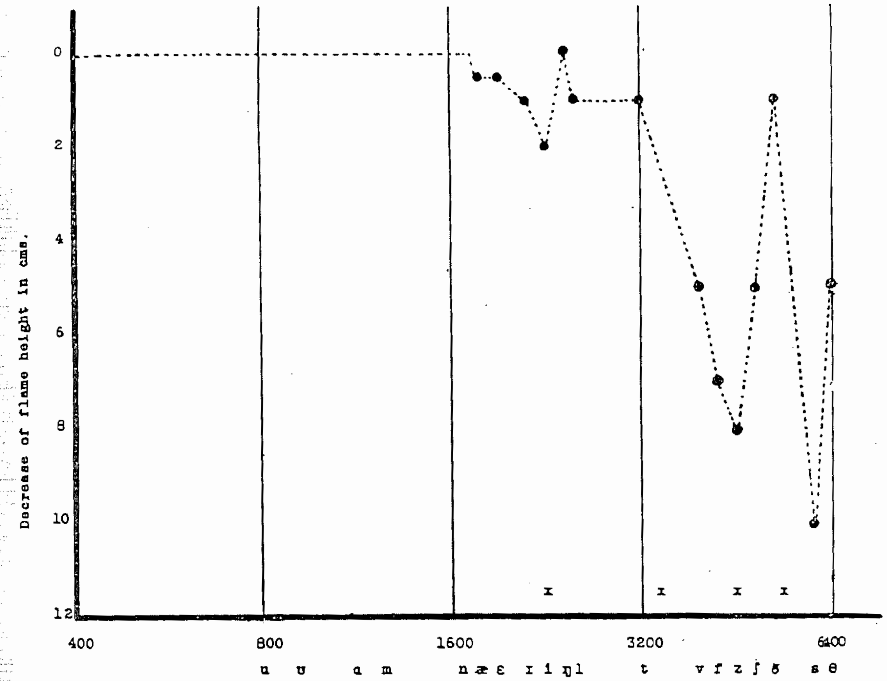

Fig. 2

frequencies should be in ascending order, and since the flames were known to be sensitive to higher rather than lower frequencies the sounds were placed according to their highest characteristic frequency. For this purpose, the data given by HARVEY FLETCHER (1) was used. A number of flames were

(1) HARVEY FLETCHER, *Speech and Hearing* (New York, 1929).

then tested by pronouncing the series of sounds and noting the response of the flame. The results obtained in this way were in many respects similar to those given by pure tones. For instance, jets of the Rayleigh and ordinary Bunsen type were sensitive only to sounds with rather low resonances — chiefly the vowels and m, n, ŋ, and l — while the plain glass jets were sensitive to the sounds with higher resonances — s, z, f, v, ʃ, ʒ etc. Again, there was found to be a great variation in the range of sounds to which different jets would respond. The most sensitive of the Bunsen jets began to respond as low as u and had so wide a range that it would also respond to ʃ and ʒ. A very sensitive glass jet, on the other hand, began to respond at the vowel æ and, at the other end of the scale, also answered to s and θ.

Fig. 2 shows the response of such a jet over the whole of the range of speech sounds used. The points marked x in the figure indicate the frequencies at which the most decided minima

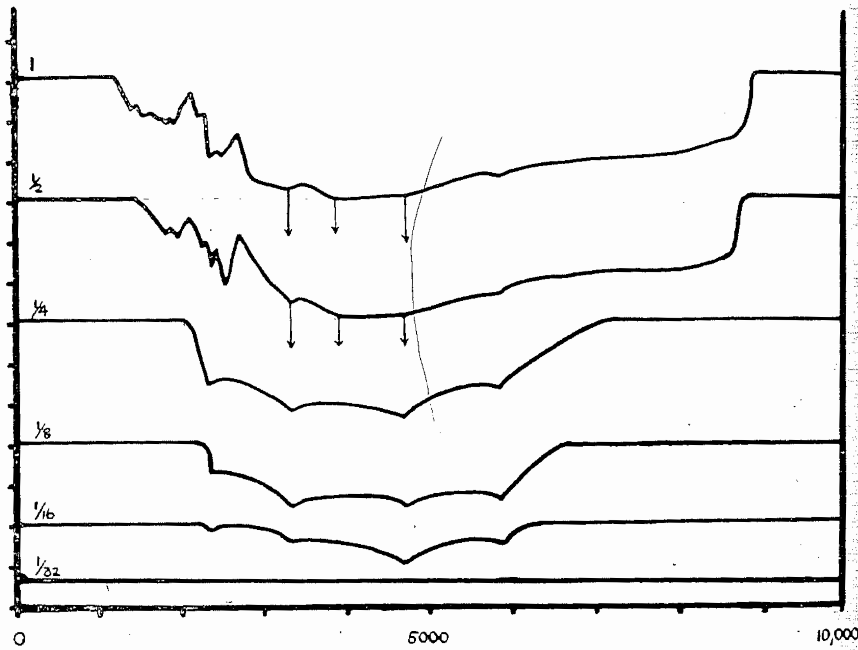

Fig. 3

occurred in Brown's investigation with pure tones. It was interesting to note that in the case of voiced sounds a change in the pitch of the voice tone appeared to have no influence upon the response of the flame. This fact seemed to bear out

the supposition that it was the characteristic resonances of the sounds which produced the response.

So far no reference has been made to the effect upon the sensitive flame of varying the amplitude of the sound to which it is subjected. It is comparatively easy to investigate this in the case of pure tones. Fig. 3 gives an idea of the effect of decreasing the amplitude of pure tones acting upon a sensitive flame. It will be seen that when the amplitude of each frequency is diminished by one half, the change in response is very slight. Even when the amplitude is reduced to one-sixteenth of its initial value, the most marked minima of the flame are still visible.

How far the amplitudes of the various speech sounds affected the response of a flame was much more difficult to determine, since the amplitude of speech sounds in general is difficult to control, and in any case it was presumably the amplitude of only one component frequency of a sound which was important. Whilst the flames were being tested for response to the list of sounds already mentioned, the practice was to keep the speaker at a fixed distance from the flame. Now since speech sounds in general differ naturally in amplitude, and since the high frequency components in particular are of different amplitudes, it might be considered that the response already quoted was a response to different frequencies, each of which had a different amplitude. It was not possible to determine how far this response was affected by these varying amplitudes, but it was found that where a flame was insensitive to a certain sound, it could not be made sensitive to it by moving the speaker right up to the flame. The opposite experiment, in which a speaker pronounced a sound to which the flame was sensitive, at increasing distances from it, gave the following result. When the speaker was at ½ m. from the flame, the decrease in height was 12 cm., at 1 m.-10 cm., at 2 m.-9 cm., at 4 m.-8 cm., at 8 m.- 6 cm. This seemed to be a further indication that the limits of amplitude within which the flame would give a marked response were rather wide.

It has sometimes been suggested that the response of a sensitive jet to a series of sounds will give a measure of the relative carrying power of the sounds. It is evident, however, from what has been said already, that such a thing is not possible, since the jets discriminate in favour of certain frequencies, and moreover two different jets would be quite capable of giving almost opposite results. Thus, for example, whilst one jet examined ducked violently for ɑ and much less for i, another responded for i and did not respond at all for ɑ.

It would be idle to pretend that the discriminating power of the flames can be utilised to make any kind of fine distinction between sounds. On the other hand, it is possible for a flame to give a visual indication of some of the more gross differences. It must be remembered that up to the present we have been considering any jet at its most sensitive, but in order to make a jet still more discriminating it is usually necessary to *reduce* its sensitivity by modifying the conditions (size or shape of orifice and pressure of gas). For example, a jet may, at its most sensitive, duck violently for the sound s and less violently but still visibly for the sound θ. It is quite possible so to narrow the range of sensitivity, by altering the gas pressure, that the response to θ disappears altogether, leaving still a marked response to s. Such a visual indication of sound difference as can be supplied in this way can be made use of where defective speech is concerned, and particularly where defective speech is the outcome of defective hearing. The patient can often be taught to produce a particular sound, but this has to be followed by long and constant practice in using it. At this stage the flame is an admirable aid since it can be a visual reminder when the right sound is used or the wrong one substituted. I have found that in English, for example, most kinds of defective s can be dealt with by using different jets — one jet would respond for s and z and not for θ and ð ; that is, it would duck six times for siks siksiz ə θəːti siks, but remained quite unresponsive to θikθ θikθið ə θəːti θikθ. Similarly other flames would discriminate between s and l̥, and s and x (some variety of the last being a common substitution by cleft-palate speakers).

Enough has perhaps been said to give some idea of what may be done with the jets. The fact that yet another flame was capable of discriminating between unaspirated and aspirated t (probably owing to the high frequency component of the aspiration) and between clear and dark l may indicate that the method could be extended still further. In any case, as was said earlier, the making of the jets is not a difficult business, and though the production of a useful one is still a matter of trial and error, yet it would seem that the field of experiment is one which might be worth exploring.

17. Prof. B. Hála (Prague) : *Nouvelles contributions à l'analyse acoustique des voyelles.*

Mesdames et Messieurs,

Dans ma brève communication je vais vous dire quelques mots sur la structure acoustique des voyelles. C'est une question délicate qui intrigue depuis longtemps déjà non seulement les

phonéticiens, mais aussi les physiciens et les physiologistes sans conduire cependant à une solution généralement admise ainsi que le montrent les deux théories vocaliques entièrement opposées l'une à l'autre : celle de Helmholtz et celle de Hermann. On peut se rappeler aussi les vives critiques qui, au commencement de notre siècle, ont été adressées aux méthodes acoustiques par l'éminent phonéticien danois, M. Jespersen.

Heureusement, beaucoup a changé depuis lors. Aujourd'hui nous possédons des procédés plus nombreux et plus perfectionnés, notamment le film parlant et l'enregistrement oscillographique ; ces nouveaux procédés sont beaucoup plus aptes à faciliter la solution du problème que l'on peut résumer succinctement en ces deux points principaux :

1° Quels sont les éléments acoustiques constituant les voyelles et

2° Lequel des deux savants a raison : Helmholtz ou Hermann.

Pour pouvoir répondre à ces deux questions j'ai mis à profit toutes les méthodes acoustiques qui m'étaient accessibles, les anciennes aussi bien que les nouvelles ; j'ai travaillé avec les résonateurs et diapasons, j'ai employé la simple ouïe et le chuchotement, j'ai fait une longue série d'enregistrements phonographiques, oscillographiques et à l'aide du film parlant ; car si l'on veut arriver à des résultats sûrs et précis, il n'est absolument pas possible de baser ses recherches sur une seule méthode et se dispenser de l'emploi laborieux des autres. J'ai suivi dans cette voie le fondateur et maître de la phonétique expérimentale l'abbé Rousselot qui, lui aussi, en s'occupant de l'étude de la structure acoustique des voyelles, avait utilisé toutes les méthodes qui à cette époque étaient à sa portée. Et ce n'est que cette façon de procéder qui nous permet le contrôle réciproque des résultats obtenus, tandis que l'emploi d'une seule méthode ne manque presque pas d'amener des résultats incomplets ou même inexacts.

Voici maintenant les résultats de mes travaux :

La *structure acoustique* des voyelles est bien complexe : les voyelles ne sont pas formées uniquement par une seule résonance habituellement appellée *note caractéristique* ou bien aussi *formant* ; cette résonance est la plus importante, c'est vrai, parce que c'est la résonance *primaire*, le son propre de la cavité buccale ayant une certaine forme d'après la position des organes phonateurs et différente d'une voyelle à l'autre. Mais, en dehors de la résonance primaire, il y a, dans chaque voyelle, trois ou quatre résonances secondaires dont les unes appartiennent à la cavité pharyngienne tandis que l'origine de certaines autres ne se laisse pas encore définir avec certitude ; pour le moment