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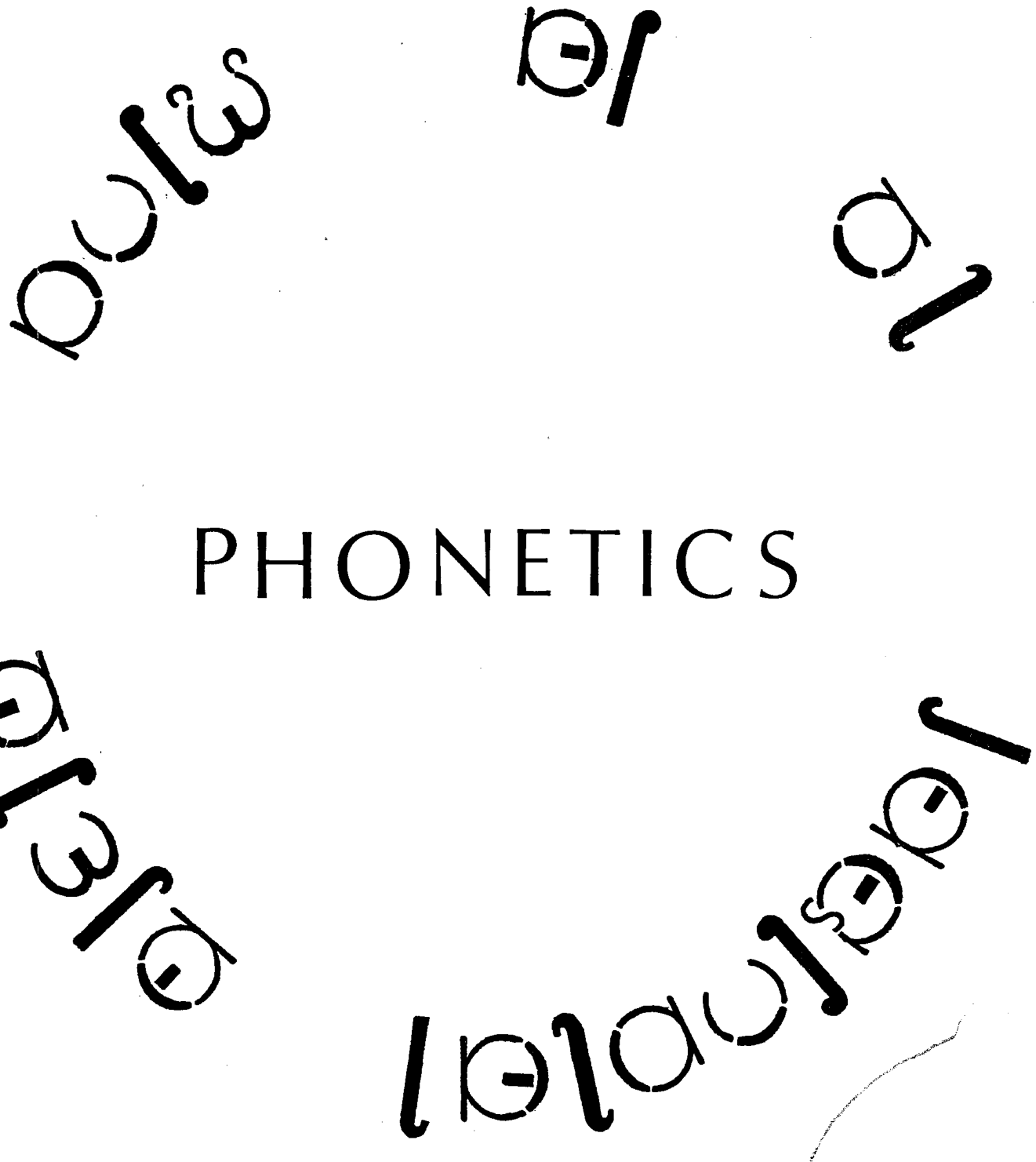

PHONETICS

PETER LADEFOGED

Working Papers in Phonetics 20

P H O N E T I C S

P e t e r L a d e f o g e d

An article on its way into a forthcoming edition of the *Encyclopaedia Britannica*

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Editorial Offices

October 8, 1971

Prof. Peter Ladefoged
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Dear Professor Ladefoged:

Thank you for your letter of September 30. There is no objection at all to your multilithing copies of your original manuscript for use by your students and a limited number of phoneticians. We would not want it to be published elsewhere ahead of our own use, but the kind of thing you are talking about is perfectly acceptable.

Thank you again for your willingness to cooperate in our work

Most sincerely,

Warren E. Preece
The General Editor
The Encyclopaedia Britannica

WEP/al

PHONETICS is the study of pronunciation. Phoneticians are not concerned with what people say, but with how they say it. The two main branches of the subject are the description of the way in which the speech organs are used to produce the sounds of speech, and the specification of the resulting sound waves. A great deal of attention is also given to studying how languages and the dialects within a language differ in the sounds they use. Phonetics is thus part of LINGUISTICS (q.v.), which is the study of human language as a whole, but its subject matter also overlaps with that of other disciplines such as physiology (v. SPEECH, PHYSIOLOGY OF), and acoustics (v. SOUND).

Knowledge of phonetics is a necessary part of linguistics, not only for the adequate description of different languages, but also for explaining the processes of word and sentence formation, and for understanding historical sound changes. Some knowledge of the subject is also useful for speech pathologists, and for teachers who are concerned with the teaching of pronunciation. Since the movements of the vocal organs are the most rapid, intricate, and precisely controlled of all human muscular activities, knowledge of the processes involved in their control is also of interest to physiologists and neurophysiologists.

STANDARDS OF PRONUNCIATION

Phoneticians are often expected to be concerned with standards of pronunciation. But from a phonetician's point of view, everybody has an accent, and there is no such thing as good or bad speech. What is called "good" speech is simply the style of speech that a class or group of people prefers. A particular form of speech may become accepted as a standard within a region, or even within a country as a whole. But what is accepted by one group may not be acceptable to another.

It should also be remembered that there are no genetic or racial characteristics which determine the way in which a child talks. As he grows up, a person usually continues to talk in the way he learned to talk during his formative years from those around him, such as his parents and his peers. An accent thus marks a person as belonging (usually by birth) to a particular group of people. With the exception of those who suffer from disorders of speech (such as cleft palate), there is nothing to prevent anybody from changing his accent, provided he devotes enough effort to the problem. In doing so he can make use of the descriptions that have been made by phoneticians of the styles of speech used by prestigious groups within a country.

Within the English speaking world there is no single way of speaking which is accepted as the most prestigious. In the United States there are several regions (e.g. New England, New York, the Appalachian Mountains, Texas, etc.) each of which have characteristic styles of speech. There seems, however, to be a growing tendency for news commentators on television and radio, actors (particularly those in commercials), and others who want to reach a wide audience throughout the country, to use a style of speech which is comparatively free of very local regional characteristics, and which is spoken by a large proportion of the population who live in the Mid-West and the Far West. This style of speech is sometimes called General American. In Britain the situation is different. In Scotland and Wales there are regional accents; but in England, as well as several local accents, there is an accent technically known as RP (Received Pronunciation, in the sense of received which means accepted at court), which is spoken all over England and indicates not what part of the country the speaker comes from, but only that he belongs to a certain social class. Other English speaking countries, such as Ireland, Canada, Australia, New Zealand, and the newly independent nations such as India, Ghana, and Nigeria, also have their own forms of English with their own regional standards.

ARTICULATORY PHONETICS

The traditional method of describing speech sounds is in terms of the movements of the vocal organs that produced them. The main structures which are important in the production of speech are the lungs and the respiratory system, together with the vocal organs shown in Figure 1. The airstream from the lungs has to pass between the vocal cords, which are two small muscular folds located in the larynx at the top of the windpipe. If the vocal cords are apart, as they are normally when breathing out, the air from the lungs will have a relatively free passage into the pharynx and the mouth. But if the vocal cords are adjusted so that there is a narrow passage between them, the airstream will cause them to be sucked together. As soon as they are together there will be no flow of air, and the pressure below them will be built up until they are blown apart again. The flow of air between them will then cause them to be sucked together again, and the vibratory cycle will continue. Sounds produced when the vocal cords are vibrating are said to be VOICED, as opposed to those in which the vocal cords are apart, which are said to be VOICELESS. The only difference between each of the pairs of words *fat, vat; thigh, thy; and Sue, zoo* is that the consonant in the first word of each pair is voiceless, whereas that in the second word is voiced.

The air passages above the vocal cords are known collectively as the vocal tract. For phonetic purposes they may be divided into the oral tract within the mouth and the pharynx, and the nasal tract within the nose. Many speech sounds are characterized by movements of the lower articulators such as the tongue or the lower lip towards the upper articulators within the oral tract. The upper surface includes several important structures from the point of view of speech

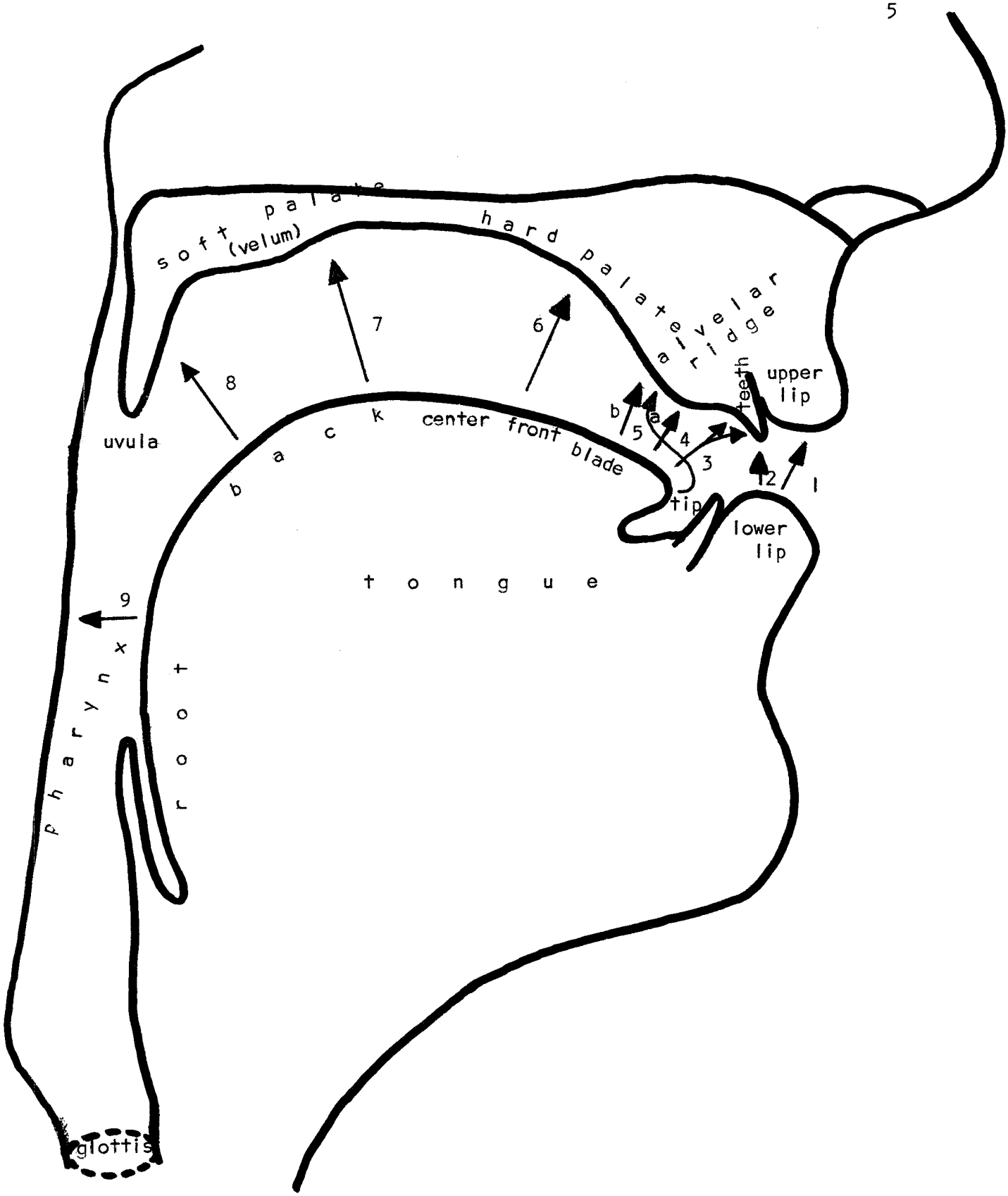

Figure 1. Some terms used in describing the vocal organs and a set of possible places of articulation; (1) Bilabial; (2) Labiodental; (3) Dental and interdental; (4) Alveolar; (5) Post-alveolar, (a) retroflex, (b) palato-alveolar; (6) Palatal; (7) Velar; (8) Uvular; (9) Pharyngal.

production; Figure 1 illustrates most of the terms that are commonly used. The upper lip and the upper teeth (notably the frontal incisors) are familiar structures and need no further comment. The alveolar ridge is a small protuberance which can easily be felt with the tongue just behind the upper front teeth. The major part of the roof of the mouth is formed by the hard palate in the front and the soft palate or velum at the back. The soft palate is a muscular flap which can be raised so as to shut off the nasal tract and prevent air from going out through the nose. When it is raised so that the soft palate is pressed against the back wall of the pharynx there is said to be a velic closure. At the lower end of the soft palate there is a small appendage hanging down which is known as the uvula.

As may be seen from Figure 1, there are also specific names for different parts of the tongue. The tip and blade are the most mobile parts. Behind the blade is what is technically called the front of the tongue; it is actually the forward part of the body of the tongue, and lies underneath the hard palate when the tongue is at rest. The remainder of the body of the tongue may be divided into the center, which is partly beneath the hard palate and partly beneath the soft palate, the back, which is beneath the soft palate, and the root, which is opposite the back wall of the pharynx.

The major division among speech sounds is that between VOWELS and CONSONANTS. Phoneticians have found it very difficult to give a precise definition of the articulatory distinction between these two classes of sounds. Most authorities would agree that a vowel is a sound in the production of which there are no major constrictions in the vocal tract, so that there is a relatively free passage for the air, and which is also SYLLABIC. This definition is unsatisfactory in that no adequate definition of the notion syllable has yet been formulated. It used to be said that each syllable is accompanied by a chest pulse, or separate push of the respiratory muscles; but this is now known to be untrue. Instead it is now generally held that a syllable is simply a unit in terms of which speech sounds are organized.

C o n s o n a n t s

In the formation of consonants, the airstream through the vocal tract is obstructed in some way. Consonants can be classified according to the place and manner of this obstruction. Some of the possible places of articulation are indicated by the arrows going from one of the lower articulators to one of the upper articulators in Figure 1. The principal terms which are required in the description of English are: BILABIAL (made with the two lips); DENTAL (tongue tip or blade and the upper front teeth); ALVEOLAR (tongue tip or blade and the teeth ridge); RETROFLEX (tongue tip and the back part of the teeth ridge);

PALATO-ALVEOLAR (tongue blade and the back part of the teeth ridge); PALATAL (front of tongue and hard palate); and VELAR (back of tongue and soft palate). The additional places of articulation shown in Figure 1 are required in the description of other languages. Note that the terms for the various places of articulation denote both which part of the lower articulators (lower lip and tongue) and which part of the upper articulatory structures are involved. Thus velar denotes a sound in which specifically the back of the tongue and the soft palate are involved; and retroflex implies a sound involving the tip of the tongue and the back part of the alveolar ridge. If it is necessary to distinguish between sounds made with the tip of the tongue, and those made with the blade, the terms APICAL (tip)and LAMINAL (blade) may be used.

There are six basic manners of articulation which can be used at these places of articulation:

1. STOP. Closure of the articulators, so that the airstream cannot go out of the mouth. This manner of articulation can be considered in terms of the two possibilities:

(a) Nasal stop. If the soft palate is down so that air can still go out through the nose, there is said to be a nasal stop. Sounds of this kind occur at the beginning of the words *my, nigh.*

(b) Oral stop. If, in addition to the articulatory closure in the mouth, the soft palate is raised so that the nasal tract is blocked off, then the airstream will be completely obstructed, the pressure in the mouth will be built up, and an oral stop will be formed. When the articulators come apart the airstream will be released with a plosive quality. This kind of sound occurs in the consonants in the words *pie, tie, kye, buy, die, guy.*

Many authorities refer to these two possibilities simply as nasals (meaning nasal stops, the closure of the articulators in the oral tract being implied), and stops (meaning oral stops, the raising of the soft palate to form a velic closure being implied).

2. FRICATIVE. Close approximation of two articulators, so that the airstream is partially obstructed and a turbulent airflow is produced. The mechanisms involved in the production of these sounds may be likened to that which occurs when the wind 'whistles' round a corner. Examples of sounds of this kind are the consonants in the words *fie, thigh, sigh, shy.* Some authorities divide fricatives into slit and grooved fricatives, or rill and flat fricatives, depending on the shape of the constriction required to produce them. Other authorities divide fricatives into sibilants (as in *sigh* and *shy)* as opposed to non-sibilants (as in *fie* and *thigh).* This division is based on acoustic criteria, which will be discussed in the next section.

3. APPROXIMANTS. The approach of one articulator towards another, but without the tract being narrowed to such an extent that a turbulent airstream is produced. The terms frictionless continuant, semivowel, and glide are sometimes used for some of the sounds made with this manner of articulation. The consonants in the words *we* and *you* are examples of approximants.

4. TRILL. An articulator loosely held fairly close to another articulator, so that it is set into vibration by the airstream. The tongue tip and blade, the uvula, and the lips are the only articulators which can be used in this way. Tongue tip trills occur in some forms of Scottish English in words such as *rye* and *ire*. Uvular trills are comparatively rare, but are used in some dialects of French (but not Parisian French). Trills of the lips are even rarer, but do occur in a few African languages.

5. TAP. One articulator thrown against another, as when the loosely held tongue tip makes a single tap against the upper teeth or the alveolar ridge. The consonant in the middle of a word such as *letter* or *Betty* is often made in this way in American English. The term FLAP is also used to describe these sounds, but some authorities distinguish between taps (defined as above) and flaps, in which the tip of the tongue is raised up and back, and then strikes the alveolar ridge as it returns to a position behind the lower front teeth. Some languages (e.g. Hausa, the principal language of Northern Nigeria) make a distinction between words containing a flap and words containing a tap. The distinction between a trill and a tap is used in Spanish to distinguish between words such as *perro* (dog) and *pero* (but).

6. LATERAL. Obstruction of the airstream in the midline of the oral tract, but incomplete closure between one or both sides of the tongue and the roof of the mouth. The sounds at the beginning and end of the word *lull* are pronounced in this way in most forms of American English.

Note that the production of many sounds involves more than one of these six basic manners of articulation. The sounds at the beginning and end of the word *church* are stops combined with fricatives. The articulators (tongue tip or blade, and alveolar ridge) come together for the stop, and then, instead of coming fully apart, separate only slightly, so that a fricative is made at the same place of articulation. This kind of combination is called an AFFRICATE. Lateral articulations may also occur in combination with other manners of articulation. The laterals in a word such as *lull* might more properly be called lateral approximants, in that the airstream passes out freely between the sides of the tongue and the roof of the mouth without a turbulent airstream being produced. But in some sounds in other languages the sides of the tongue are closer to the roof of the mouth and a lateral fricative occurs; an example is the sound spelled *ll* in Welsh words such as *llan* (church) and the name *Lluellyn*.

When an approximant articulation occurs at the same time as another articulation is being made at a different place in the vocal tract, the approximant is said to form a SECONDARY ARTICULATION. There are special terms for some of these possibilities. Added lip rounding is called LABIALIZATION; it occurs in the formation of several English sounds, e.g. during the palato-alveolar fricative at the beginning of the word *shoe*. Raising of the front of the tongue while simultaneously making another articulation elsewhere in the vocal tract is called PALATALIZATION. It is the distinguishing characteristic of the soft consonants in Russian, and also occurs, to a lesser extent in English, in e.g. the first consonant in the word *leaf*. Raising of the back of the tongue to form a secondary articulation is called VELARIZATION; it occurs in the last consonant in the word *feel* (which therefore does not contain the same sounds as in the word *leaf* in the reverse order). Retracting of the root of the tongue while making another articulation is called PHARYNGALIZATION; it occurs in Arabic in what are called emphatic consonants.

The states of the glottis, places of articulation, and manners of articulation discussed above are sufficient to distinguish between the major contrasts among the consonants of English and many other languages. But additional possibilities have to be taken into account in more detailed descriptions of English, or in descriptions of several other languages. Among these possibilities are variations in the timing of the states of the glottis. As well as the contrast between the voiced and voiceless states of the glottis which occur during an articulation, there may be variations in the state of the glottis during the release of the articulation. Thus both the *p* in *pin* and that in *spin* are voiceless bilabial stops; but they differ in that the glottis remains in a voiceless position for a short time after the release of the bilabial stop in *pin*, whereas in *spin* the voicing starts as soon as the lips come apart. When there is a period of voicelessness during the release of an articulation, the sound is said to be ASPIRATED. The main difference between the consonants in *pea* and *bee* (when these words are said in isolation) is not that the one is voiceless and the other voiced, but that the first is aspirated and the second is unaspirated. Some languages use both voiced - voiceless and aspirated - unaspirated distinctions between sounds. Thus Thai has contrasts between voiceless aspirated stops, voiceless unaspirated stops, and voiced unaspirated stops.

Several languages use more than just the voiced and voiceless states of the glottis. In Hindi and many of the other languages of India some sounds are produced while the vocal cords are vibrating for part of their length, but are apart so that a considerable amount of air escapes between them at one end. This kind of phonation is known as breathy voice, or murmur. Yet other languages have sounds

in which the vocal cords are held tightly together so that only part of their length can vibrate. This kind of sound, which is usually very low pitched, is sometimes called creaky voice, or vocal fry. It is used to make contrasts between consonants in several American Indian languages. An additional glottal state which is widely used (e.g. in the Malayo-Polynesian languages of the Philippines) is a glottal stop, a tight closure of the two vocal cords. This articulation occurs also in many forms of English as the usual pronunciation of *t* in words such as *bitten* and *fatten.*

In English, all sounds are produced with an airstream caused by the expiration of the air from the lungs. This is known as a PULMONIC airstream. Other mechanisms for producing an airstream also occur. If there is a glottal stop and the closed glottis is moved rapidly upwards or downwards it can act like a piston pushing or pulling the air in the pharynx. This is the GLOTTALIC airstream mechanism. When there is an upward movement of the closed glottis the resulting sound is called an EJECTIVE. Amharic, the national language of Ethiopia, uses this mechanism to produce both ejective stops and fricatives, which contrast with the more usual stops and fricatives made with a pulmonic airstream mechanism. A downward movement of the glottis is used in the production of IMPLOSIVE sounds, which occur in many American Indian, African, and other languages. It is also possible to use movements of the tongue to suck air into the mouth. This is known as the VELARIC airstream mechanism. It occurs in the production of CLICKS (q.v.) which are regular speech sounds in many of the languages spoken in Southern Africa.

To summarize, a consonant may be described by reference to seven factors: (1) state of the glottis; (2) secondary articulation (if any); (3) place of articulation; (4) type of airstream; (5) central or lateral articulation; (6) velic closure (oral or nasal); (7) manner of articulation. Thus the consonant at the beginning of the word *swim* is a (1) voiceless, (2) labialized, (3) alveolar, (4) pulmonic, (5) central, (6) oral, (7) fricative. Unless a specific statement is made to the contrary, consonants are usually presumed to have no secondary articulation, and a pulmonic airstream, and not to be laterals or nasals. Consequently points (2, 4, 5, 6) are often disregarded and a three term description (such as voiceless alveolar fricative for the first consonant in *sin)* is sufficient.

V o w e l s

Vowels have traditionally been specified in terms of the position of the highest point of the tongue and the position of the lips. Figure 2 shows these positions for eight different vowels. The highest point of the tongue is in the front of the mouth for the vowels in *heed, hid, head* and *had.* Accordingly these vowels are classified as FRONT vowels, whereas the vowels in *hod, hawed, hood* and *who'd* are classified as

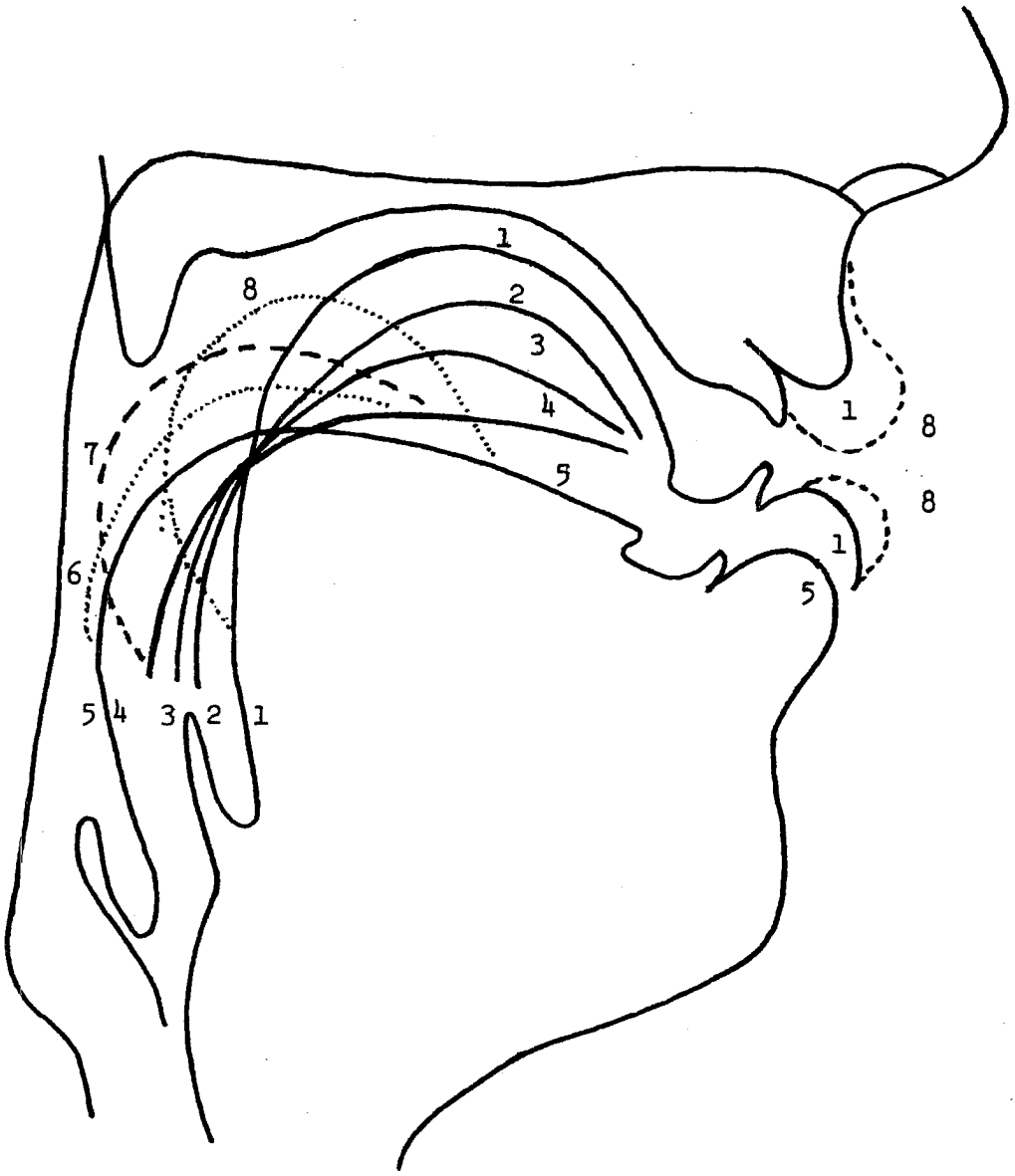

Figure 2. The tongue positions in the vowels in the words: (1) *heed*, (2) *hid*, (3) *head*, (4) *had*, (5) *hod*, (6) *hawed*, (7) *hood*, (8) *who'd*.

BACK vowels. The tongue is highest in the vowels in *heed* and *who'd* (which are therefore called HIGH, or close, vowels), and lowest in the vowels in *had* and *hod* (which are called LOW, or open, vowels). The height of the tongue for the vowels in the other words is between these two extremes, and they are therefore called MID vowels. Lip positions may be described as being ROUNDED (as in *who'd*) or UNROUNDED or spread (as in *heed).*

The specification of vowels in terms of the position of the highest point of the tongue is not entirely satisfactory for a number of reasons. In the first place it disregards the fact that the shape of the tongue as a whole is very different in front vowels and in back vowels. Secondly, although the height of the tongue in front vowels varies by approximately equal amounts for what are called equidistant steps in vowel quality, this is just not factually true in descriptions of back vowels. Thirdly, the width of the pharynx varies considerably, and to some extent independently of the height of the tongue in different vowels.

Some authorities use terms such as TENSE and LAX to describe the degree of tension in the tongue muscles, particularly those muscles responsible for the bunching up of the tongue lengthways. Other authorities use the term tense to specify a greater degree of muscular activity, resulting in a greater deformation of the tongue from its neutral position. Tense vowels are longer than the corresponding lax vowels. The vowels in *heed,* and *hayed* are tense, whereas those in *hid* and *head* are lax.

In the languages of the world there is a strong tendency for front vowels to have spread lip positions, and back vowels to have lip rounding. As will be seen in the next section, this results in vowels which are acoustically maximally distinct. But many languages (e.g. French and German) have front rounded vowels. Thus French has a contrast between a high front unrounded vowel as in *vie* (life), and a high front rounded vowel with a very similar tongue position as in *vu* (seen), as well as a high back rounded vowel as in *vous* (you). Unrounded back vowels also occur (e.g. in Vietnamese).

NASALIZED vowels, in which the soft palate is lowered so that part of the airstream goes out through the nose, occur in many languages. French distinguishes between several nasalized vowels and vowels made with similar tongue positions but with the soft palate raised. Low vowels in many forms of English are often nasalized, especially when they occur between nasal consonants, as in *man.*

Because of the difficulty of observing the precise tongue positions which occur in vowels, a set of eight vowels known as the CARDINAL VOWELS was devised by the phonetician Daniel Jones (q.v.) to act as reference points. This set of vowels is defined partly in articulatory and partly in auditory terms. Cardinal vowel number one

is defined as the highest and most front tongue position which can be made without producing a fricative sound; and cardinal vowel number five is defined as the lowest and most back possible vowel. Cardinal vowels two, three, and four are a series of front vowels such that they form auditorilly equidistant steps between cardinal vowels one and five; and cardinal vowels six, seven, and eight are a series of back vowels with the same size auditory steps as in the front vowel series. Phoneticians who have been trained in the cardinal vowel system are able to make precise descriptions of the vowels of any language in terms of these reference points.

Suprasegmentals

Vowels and consonants can be considered to be the segments of which speech is composed. Together they form the syllables, which go to make up utterances. Superimposed on the syllables there are other features which are known as suprasegmentals. These include variations in stress (accent), and pitch (tone and intonation). Variations in length are also usually considered to be suprasegmental features although they can affect single segments as well as whole syllables. All the suprasegmental features are characterized by the fact that they must be described in relation to other items in the same utterance. It is the relative values of the pitch, length, or degree of stress of an item which are significant. The absolute values are never linguistically important, although they may be of importance paralinguistically, in that they convey information about the age and sex of the speaker, his emotional state, and his attitude to the topic under discussion.

Many languages (e.g. Finnish and Estonian) use length distinctions, so that they have long and short vowels; and a slightly smaller number (e.g. Japanese and Luganda, the language spoken by the largest tribe in Uganda) also have long and short consonants. In most languages segments followed by voiced consonants are longer than those followed by voiceless consonants. Thus the vowel in *cad* is much longer than that in *cat*.

Variations in stress are caused by an increase in the activity of the respiratory muscles (so that a greater amount of air is pushed out of the lungs) and in the activity of the laryngeal muscles (so that there is a significant change in pitch). Stress has a grammatical function in English, distinguishing between nouns and verbs (such as *an insult* vs. *to insult*). It can also be used for contrastive emphasis (as in *I want a RED pen, not a black one*).

Variations in laryngeal activity can occur independently of stress changes. When they do so the resulting pitch changes can affect the meaning of the sentence as a whole, or the meaning of the individual words. The pitch pattern in a sentence is known as the INTONATION. In English the meaning of a sentence such as *That's a cat* can be changed from a statement to a question by the substitution of a mainly rising for a mainly falling intonation. Pitch patterns that affect the meanings of individual words are known as TONES. They do not occur in English, but they are common in many other languages. In

Chinese, a syllable which could be written in our orthography as *ma* means "mother" if it is said on a high tone, "hemp" if it is said on a mid-rising tone, "horse" if it is said on a falling-rising tone, and "scold" if it is said on a high falling tone.

ACOUSTIC PHONETICS

Speech sounds consist of small variations in air pressure that can be sensed by the ear. Like other sounds, speech sounds can be divided into two major classes: those that have periodic waveforms (regular fluctuations in air pressure); and those that do not. The first class consists of all the voiced sounds, since the vibrations of the vocal cords produce regular pulses of air pressure.

From a listener's point of view, sounds may be said to vary in pitch, loudness, and quality. The pitch of a sound with a periodic waveform (i.e. a voiced sound) is determined by its fundamental frequency, or rate of repetition of the cycles of air pressure. For a speaker with a bass voice the fundamental frequency will probably be between 75 and 150 cycles per second (or Hertz [= Hz], to use the standard term for the unit in frequency measurements). A soprano may have a speaking voice in which the vocal cords vibrate to produce a fundamental frequency of over 400 Hz. The relative loudness of a voiced sound is largely dependent on the amplitude of the pulses of air pressure produced by the vibrating vocal cords.

The quality of a sound is determined by the smaller variations in air pressure which are superimposed on the major variations that recur at the fundamental frequency. Every time the vocal cords open and close there is a pulse of air from the lungs. These pulses act like sharp taps on the air in the vocal tract, which is accordingly set into vibration in a way which is determined by its size and shape. In a vowel sound, the air in the vocal tract vibrates at three or four frequencies simultaneously. These frequencies are the resonant frequencies of that particular vocal tract shape. Irrespective of the rate of vibration of the vocal cords, the air in the vocal tract will resonate at these three or four frequencies as long as the position of the vocal organs remains the same. In this way a vowel has its own characteristic auditory quality, which is the result of the specific variations in air pressure due to its vocal tract shape being superimposed on the fundamental frequency produced by the vocal cords.

The resonant frequencies of the vocal tract are known as the formants. The frequencies of the first three formants of the vowels in the words *heed, hid, head, had, hod, hawed, hood, who'd* are shown in Figure 3. Comparison of this figure with Figure 2 shows that there are no simple relationships between actual tongue positions and formant frequencies. There is, however, a good inverse correlation between one of the labels used to describe the tongue position and the

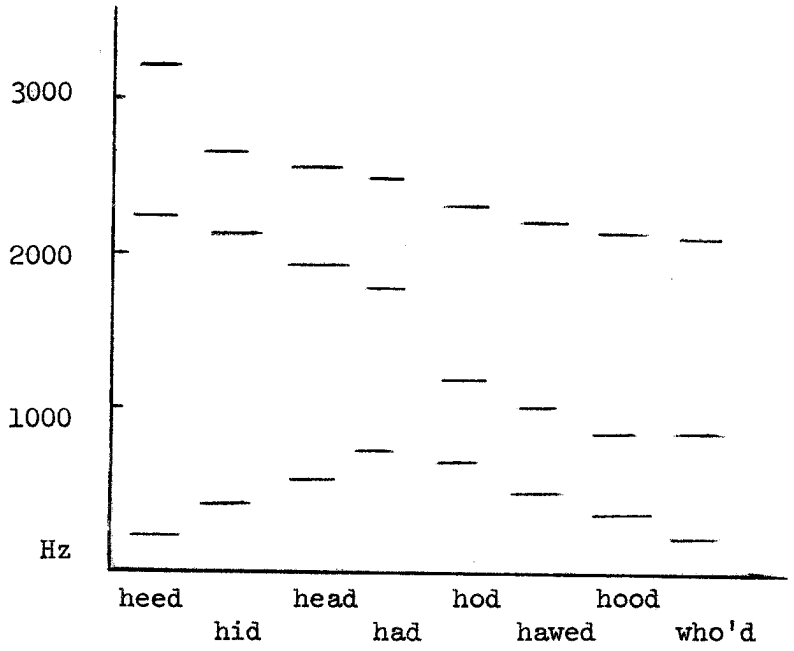

Figure 3. A schematic spectrogram showing the frequencies of the first three formants of the vowels in some English words.

frequency of the first (lowest) formant. This formant is lowest in the so-called high vowels, and highest in the so-called low vowels. It seems probable that when phoneticians describe vowels as high or low what they are actually doing is specifying the inverse of the frequency of the first formant.

Most people cannot hear the pitches of the individual formants in normal speech. But in whispered speech there are no regular variations in air pressure produced by the vocal cords, and the higher resonances of the vocal tract are more clearly audible. It is quite easy to hear the falling pitch of the second formant when whispering the series of words *heed, hid, head, had, hod, hawed, hood, who'd.* Conversely, the auditory effect of the second and higher formants is lessened when speaking in a creaky voice. It is possible to hear the rise in pitch of the first formant during the first four of these words, and the fall in pitch during the last four of these words when the series is spoken with this kind of phonation.

Voiced consonants such as nasal and laterals also have specific vocal tract shapes which are characterized by the frequencies of the formants. They differ from vowels in that in their production the vocal tract is not a single tube. There is a side branch formed when the nasal tract is coupled in with the oral tract, or, in the case of laterals, when the oral tract itself is obstructed in the center. The effect of these side branches is that the relative amplitudes of the formants are altered; it is as if one or more of the possible superimposed variations in air pressure had been lessened because it had been trapped in the cavity formed at the side. Nasal and laterals can therefore be specified in terms of their formant frequencies, just like vowels. But in a complete specification of these consonants the relative amplitudes of the formants also have to be given, since they are not completely predictable.

Other voiced consonants such as stops and approximants (semivowels) are more like vowels in that they can be characterized in part by the resonant frequencies (the formants) of their vocal tract shapes. They differ from vowels in that during a voiced stop closure there is very little acoustic energy, and during the release of a stop and the whole of a semivowel the vocal tract shapes are changing comparatively rapidly. These transitional movements in consonants can be specified acoustically in terms of the movements of the formant frequencies.

Voiceless sounds do not have a periodic waveform with a well defined fundamental frequency. Nevertheless some sensations of pitch accompany the variations in air pressure caused by the turbulent airflow which occurs during a voiceless fricative, or in the release phase of a voiceless stop. This is because the pressure variations

are far from random. During the first consonant in *sea* they have a tendency to be at a higher center frequency (and hence a higher pitch) than in the first consonant in *she*. There is also a difference in the average amplitude of the waveform in different voiceless sounds. All of them have much less energy (a smaller amplitude) than voiced sounds pronounced with the same degree of effort. The fricative mechanisms for producing acoustic energy are far less efficient than the vocal cord mechanism for producing variations in air pressure. But some fricative mechanisms are more efficient than others. Other things being equal, the fricatives in *sin* and *shin* have more amplitude (are louder) than those in *thin* and *fin*.

In summary, speech sounds are fairly well defined by nine acoustic factors: (1, 2, 3) The frequencies of the first three formants, which characterize the vocal tract shape and hence specify vowels, nasals, laterals, and the transitional movements in voiced consonants. The frequencies of the fourth and higher formants do not vary very much. The first three formants are responsible for the major part of the information in speech. (4) The fundamental frequency (roughly speaking, the pitch) of the larynx pulse in voiced sounds; and (5) the amplitude (roughly speaking, the loudness) of the larynx pulse. These two factors account for suprasegmental information such as variations in stress and intonation. They also distinguish between voiced and voiceless sounds, in that the latter have no larynx pulse amplitude. (6) The center frequency of the high frequency hissing noises in voiceless sounds; and (7) the amplitude of these high frequency noises. These two factors characterize the major differences among voiceless sounds. In more accurate descriptions it would be necessary to specify more than just the center frequency of the noise in fricative sounds. (8,9) The amplitudes of the second and third formants relative to the first formant (the amplitudes of the formants as a whole being determined by the larynx pulse amplitude). These two factors are the least important in that they convey only supplementary information about nasals and laterals.

The principal instrument used in acoustic phonetic studies is the SOUND SPECTROGRAPH. This device gives a visible record of any kind of sound. A spectrographic analysis of the phrase *speech pictures* is shown in Figure 4. The time of occurrence of each item is given on the horizontal scale. The vertical scale shows the frequency components at each moment in time, the amplitude of the components being shown by the darkness of the mark. (Figure 3 diagrammed the formant frequencies in a set of English vowels in the same way, and could be regarded as a schematic spectrogram.) In the phrase *speech pictures* the first consonant has a comparatively random distribution of energy; but as Figure 4 shows, it is mainly in the higher frequencies.

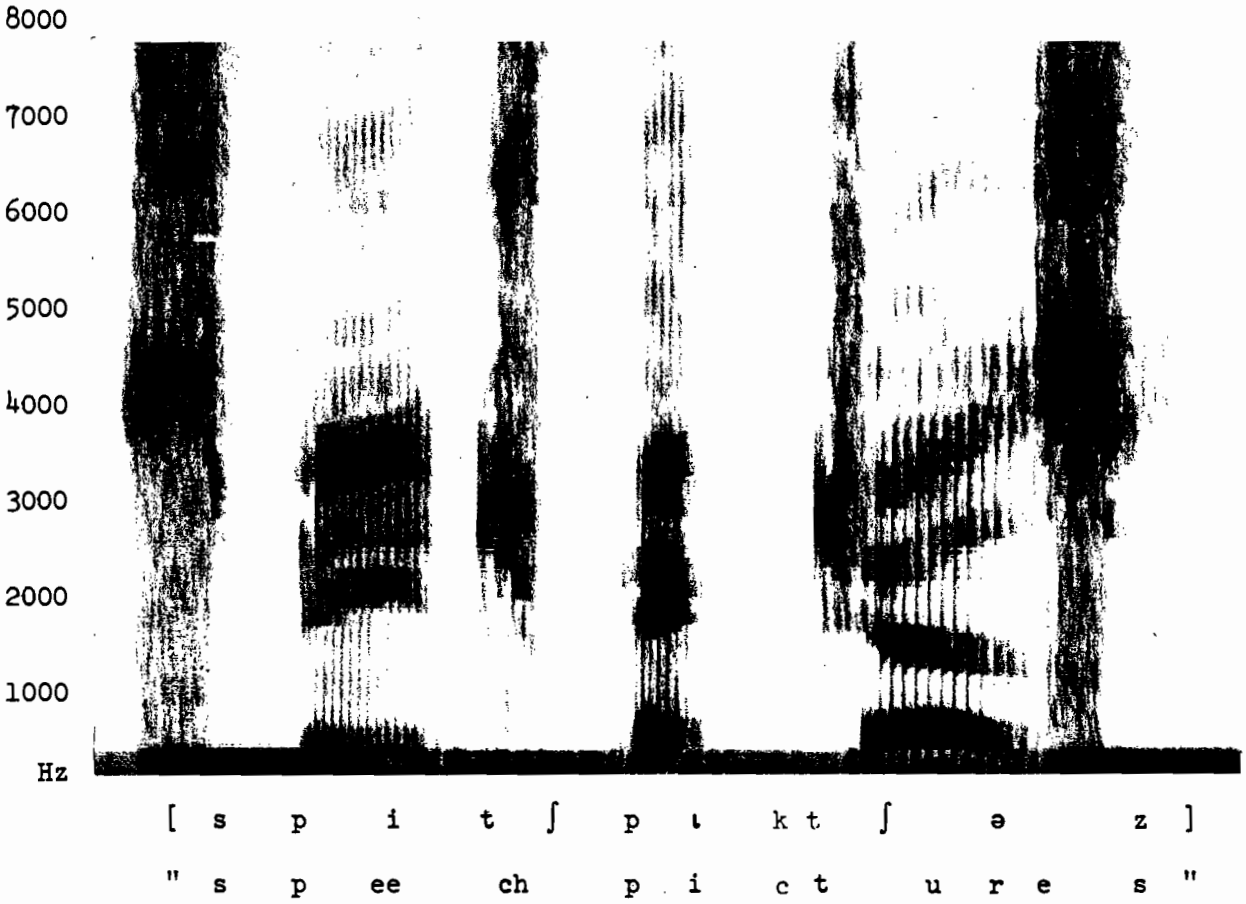

Figure 4. A spectrogram of the phrase "speech pictures". The horizontal dimension represents time, and the vertical scale represents frequency. The amplitude of the component frequencies at each moment in time is shown by the darkness of the mark.

The second consonant is a voiceless stop, which produces a short gap in the pattern. The next segment, the first vowel, has four formants which appear as dark bars with center frequencies of 300, 2,000, 2,700 and 3,400 Hz. Each of the other segments has its own distinctive pattern.

Much information has also been gained from the use of SPEECH SYNTHESIZERS, which are instruments that take specifications of speech in terms of acoustic factors such as those summarized above and generate the corresponding sounds. Some speech synthesizers use electronic signal generators and amplifiers, whereas others use digital computers to calculate the values of the required sound waves. Good synthetic speech is extremely hard to distinguish from high quality recordings of natural speech. The principle value of a speech synthesizer is that it provides a precisely controllable "voice" which an experimenter can vary in a systematic way in order to determine the perceptual effects of different acoustic specifications. It is also possible to use a speech synthesizer to generate speech from an ordinary typewritten input, using a stored table of values for each sound, and a set of rules which specify the relations between the input letters, the stored table, and the output sound waves.

LINGUISTIC PHONETICS

Phonetics is part of linguistics in that one of the main aims of the subject is to determine the categories which can be used in explanatory descriptions of languages. One way of looking at the grammar of a language is to consider it to be a set of statements which explains the relation between the meanings of all possible sentences in a language, and the sounds of which they are composed. In this view, a grammar may be divided into three parts: the syntactic component, which is a set of rules describing the ways in which words may form sentences; the lexicon, which is a list of all the words and the categories to which they belong; and the phonological component, which is a set of rules which relates phonetic descriptions of sentences to the syntactic and lexical descriptions.

In the lexicon of a language, each word is represented in its underlying, or basic, form, which discounts all the alternations in pronunciation which are predictable by phonological rules. For example, there are phonological rules which will account for the variations in the placement of stress, and for the alternations of vowel quality, which occur in sets of words such as *harmOny, harmOnic, harmOnious* and *melOdy, melOdic, melOdious*. The rules which predict the pronunciation of the capitalized *O's* are general, and the grammar should state such rules so that the regularities are revealed. Accordingly, each of these words must be entered in the lexicon in a way that represents simply its underlying form, and which allows the alternations which occur to be generated by phonological rules. The underlying form is

known as the phonemic (sometimes morphophonemic, or phonological) representation of the word. The PHONEMES of a language are the segments which contrast in the underlying forms. American English may be said to have at least thirteen vowel phonemes, which contrast in the underlying forms of words such as *bate, bat, beat, bet, bite, bit, bout, but, boat, dot, bought, balm, boy.* Some authorities consider that there are additional vowel phonemes exemplified in the words *bush, beaut(y);* but others believe these are rule governed variants of the same underlying vowel as that in the word *bud.*

The variants of phonemes which occur in phonetic representations of sentences are known as ALLOPHONES. They may be considered to be generated as a result of applying the phonological rules to the phonemes in underlying forms. For example there is a phonological rule of Enlish which says that a voiceless stop such as /p/ is aspirated when it occurs at the beginning of a word (e.g. in *pin),* but when it occurs after a voiceless alveolar fricative (= /s/) it is unaspirated (e.g. in *spin);* thus the underlying phoneme /p/ has an aspirated and an unaspirated allophone (in addition to other allophones which are generated as a result of other rules which apply in other circumstances).

In stating phonological rules it is necessary to refer to classes of phonemes. Consider part of the rule for the formation of the plural in English. The fact is that there is an extra vowel in the suffix if the word ends in the same sound as occurs at the end of one of the words *horse, maze, fish, rouge, church,* or *judge.* The plural forms of words of this kind are one syllable longer than the singular forms. The phonological rules of English could simply list the phonemes which behave in the same way in the rules for plural formation (and also in the rules for the possessive forms of nouns and for the third person singular of the present tense of a verb, which are similar in this respect). But the rules are more explanatory if they show that these phonemes behave in a similar way because they form a natural class, or set, whose members are defined by a common property. In this case the phonemes are all and only those which have a high frequency fricative component; they may be called the sibilant or strident phonemes.

Other phonological rules which refer to natural classes of phonemes have already been mentioned. The rule about voiceless stops being aspirated in some circumstances and unaspirated in others refers to the subset of phonemes which are both voiceless and stops. Similarly the variations in vowel length in *cat* and *cad* can be stated in terms of a rule which refers to the set of phonemes which are vowels, and also to the set which is both voiceless and stops.

Each of the phonemes which appears in the lexicon of a language may be classified in terms of a set of phonetic properties, or FEATURES. Phoneticans and linguists have been trying to establish a complete set of features which is sufficient to classify the phonemes in each of the languages of the world. A set of features of this kind would constitute

Table 1. Part of the set of features proposed by Chomsky and Halle (1968)

Major class features

Consonantal
Syllabic
Sonorant

Cavity features

Nasal
Lateral

Anterior
Coronal

Manner of articulation features

Continuant
Delayed release
Tense

High
Low
Back

Round

Source features

Voice
Strident

Table 2. The distinctive feature composition of some English segments

	i	u	e	ɑ	ɪ	w	r	l	p	t	d	θ	ð	n	s	z	ʃ	k	h
syllabic	+	+	+	+	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-
consonantal	-	-	-	-	-	-	+	+	+	+	+	+	+	+	+	+	+	+	-
high	+	+	-	-	+	+	-	-	-	-	-	-	-	-	-	-	+	+	-
back	-	+	-	+	-	+	-	-	-	-	-	-	-	-	-	-	-	+	-
low	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+
anterior	-	-	-	-	-	-	-	+	+	+	+	+	+	+	+	+	-	-	-
coronal	-	-	-	-	-	-	+	+	-	+	+	+	+	+	+	+	+	-	-
round	-	+	-	-	-	+												-	
tense	+	+	+	+	-	-													
voice							+	+	-	-	+	-	+	+	-	+	-	-	-
continuant							+	+	-	-	-	+	+	-	+	+	+	-	+
nasal							-	-	-	-	-	-	-	+	-	-	-	-	-
strident							-	-	-	-	-	-	-	-	+	+	+	-	-
lateral							-	+	-	-	-	-	-	-	-	-	-	-	-

the phonetic capabilities of man. To be descriptively adequate from a linguistic point of view the set of features must be able to provide a different representation for each of the words which is phonologically distinct in a language; and if the feature set is to have any explanatory power it must also be able to classify phonemes into appropriate natural classes as required in the phonological rules of each language.

In the earlier work on feature sets emphasis was placed on the fact that features were the smallest discrete components of language. Not much attention was paid to their role in classifying phonemes into the natural classes required in phonological rules. Instead they were considered to be the units to which a listener attends when listening to speech. Features were justified by reference to their role in distinguishing phonemes in minimal sets of words such as *Bill, pill, fill, mill, dill, sill, kill.*

As a result of studying the phonemic contrasts within a number of languages, Jakobson, Fant and Halle (1951) concluded that segmental phonemes could be characterized in terms of 12 distinctive features. All the features were binary, in the sense that a phoneme either had, or did not have, the phonetic attributes of the feature. Thus phonemes could be classified as being consonantal or not, voiced or not, nasal or not, and so on. More recently Chomsky and Halle (1968) concluded that nearer 30 features are needed for a proper description of the phonetic (and linguistic) capabilities of man. They also claim that each feature functions as a binary opposition, which can be given the value plus or minus in classifying the phonemes in underlying forms; but they suggest that the features must be specified more precisely in systematic phonetic specifications.

Some of the binary features proposed by Chomsky and Halle are listed in Table 1. The first group are called major class features, since they are required for dividing sounds into classes such as vowels, consonants, and semivowels. There are several problems in giving satisfactory definitions of the phonetic properties of these features; but there is no doubt that binary oppositions of this kind are needed for describing the phonological patterns that occur in languages.

The next group, the manner of articulation features, include continuant-noncontinuant, where noncontinuant is exactly equivalent to the notion stop as defined in an earlier section; and delayed release, which refers to the comparatively slow parting of the articulators which occurs in an affricate. The feature tense (as opposed to lax) refers to the degree of tension of the muscles; some authorities consider it should be restricted to the specification of the degree of tension of the tongue muscles. The third group, the source features, refer to the action of the vocal cords (voice) or to fricative noise mechanisms (strident).

The cavity features include nasal and lateral, which are used as defined in the section on articulatory phonetics, and the features which determine the place of articulation of consonants and the quality of vowels. The most important features specifying the place of articulation of consonants are anterior (made in the front of the mouth) and coronal (made with the tip or blade of the tongue raised towards the teeth or teeth ridge). These two features can be used to specify four places of articulation: bilabial (+ anterior, - coronal); dental or alveolar (+ anterior, + coronal); post alveolar or palato-alveolar (- anterior, + coronal); velar (- anterior, - coronal). There is still some disagreement over whether consonantal places of articulation are specified appropriately by binary oppositions of this kind.

There is even more disagreement over the advisability of describing vowels in terms of binary features. Chomsky and Halle use the features high - nonhigh and low - nonlow to specify the height of the tongue, mid tongue positions being considered to be simply those which are (- high, - low); and they use the feature back - nonback to specify the front - back distinctions among vowels. But these three features can be combined to specify only six basic tongue positions: high front, high back, mid front, mid back, low front and low back. It is true that each of these possibilities can have tense - nontense (lax) variants and rounded - nonrounded (spread) variants. But the Chomsky-Halle feature system does not permit the specification within underlying forms of either central vowels, or more than three degrees of tongue height. Moreover their binary oppositions of vowel height do not make it clear that the difference between low vowels and mid vowels is the same as that between mid vowels and high vowels.

Table 2 shows the feature composition of a number of segments which occur in English. The phonetic symbols at the top of each column are used with the values given in the next section.

PHONETIC TRANSCRIPTION

There are many different kinds of phonetic transcription. In some circumstances a phonetic symbol can be simply an abbreviation for a phonetic description. The symbol [s] may then be regarded as exactly equivalent to the phrase "voiceless, alveolar, fricative." When a linguist goes into the field to describe an unknown language he begins by writing it down using symbols in this way. Later, when he has learnt about the function of sounds and the underlying forms in the language, he might make a more systematic transcription, in which each phoneme was represented by a simple symbol. This kind of transcription is known as a BROAD TRANSCRIPTION.

THE INTERNATIONAL PHONETIC ALPHABET.

(Revised to 1951.)

		Bi-labial	*Labio-dental*	*Dental and Alveolar*	*Retroflex*	*Palato-alveolar*	*Alveolo-palatal*	*Palatal*	*Velar*	*Uvular*	*Pharyngal*	*Glottal*
CONSONANTS	*Plosive*	p b		t d	ʈ ɖ			c ɟ	k g	q ɢ		ʔ
	Nasal	m	ɱ	n	ɳ			ɲ	ŋ	ɴ		
	Lateral Fricative			ɬ ɮ								
	Lateral Non-fricative			l	ɭ			ʎ				
	Rolled			r						ʀ		
	Flapped			ɾ	ɽ					ʀ		
	Fricative	ɸ β	f v	θ ð | s z | ɹ	ʂ ʐ	ʃ ʒ	ɕ ʑ	ç j	x ɣ	χ ʁ	ħ ʕ	h ɦ
	Frictionless Continuants and Semi-vowels	w | ɥ	ʋ	ɹ				j (ɥ)	(w)	ʁ		

VOWELS	*Front*	*Central*	*Back*
Close	i y	ɨ ʉ	ɯ u
Half-close	e ø	ɘ	ɤ o
Half-open	ɛ œ	ɜ	ʌ ɔ
Open	æ	ɐ	a ɑ ɒ

(Secondary articulations are shown by symbols in brackets.)

OTHER SOUNDS.—Palatalized consonants: tʲ, dʲ, etc.; palatalized ʃ, ʒ: ʃʲ, ʒʲ. Velarized or pharyngalized consonants: ɬ, ɖ, z, etc. Ejective consonants (with simultaneous glottal stop): p', t', etc. Implosive voiced consonants: ɓ, ɗ, etc. ʀ fricative trill. σ, ʒ (labialized θ, ð, or s, z). ɬ, ɮ (labialized ʃ, ʒ). ʇ, ʗ, ʖ (clicks, Zulu *c*, *q*, *x*). ɺ (a sound between r and l). ɳ Japanese syllabic nasal. ʃ (combination of x and ʃ). ʍ (voiceless w). ɪ, ʏ, ʊ (lowered varieties of i, y, u). ɜ (a variety of ə). ɵ (a vowel between ø and o).

Affricates are normally represented by groups of two consonants (ts, tʃ, dʒ, etc.), but, when necessary, ligatures are used (ʦ, ʧ, ʤ, etc.), or the marks ‿ or ⁀ (t͡s or t‿s, etc.). ‿ ⁀ also denote synchronic articulation (m͡ɱ = simultaneous m and ɱ). c, ɟ may occasionally be used in place of tʃ, dʒ, and ʧ, ʤ for ʦ, ʣ. Aspirated plosives: pʰ, tʰ, etc. r-coloured vowels: eɹ, aɹ, ɔɹ, etc., or eʴ, aʴ, ɔʴ, etc., or e˞, a˞, ɔ˞, etc.; r-coloured ə: əɹ or əʴ or ɹ or ə˞ or ɚ.

LENGTH, STRESS, PITCH.— : (full length). ˑ (half length). ˈ (stress, placed at beginning of the stressed syllable). ˌ (secondary stress). ˉ (high level pitch); ˍ (low level); ˊ (high rising); ˌ (low rising); ˋ (high falling); ˏ (low falling); ˆ (rise-fall); ˇ (fall-rise).

MODIFIERS.— ̃ nasality. ̥ breath (l̥ = breathed l). ̬ voice (s̬ = z). ʰ slight aspiration following p, t, etc. ʷ labialization (n̪ = labialized n). ̪ dental articulation (t̪ = dental t). ʲ palatalization (ż = ʒ). ̣ specially close vowel (ẹ = a very close e). ̩ specially open vowel (ę = a rather open e). ˕ tongue raised (e˕ or ę = ẹ). ˔ tongue lowered (e˔ or ę = ę). ˖ tongue advanced (u˖ or u̟ = an advanced u, t̠ = t̪). ˗ or ̠ tongue retracted (i˗ or i̠ = ɨ˖, t̠ = alveolar t). › lips more rounded. ‹ lips more spread. Central vowels: ÿ (= ɨ), ü (= ʉ), ë (= ə˕), ö (= ɵ), ë, ö. ̩ (e.g. n̩) syllabic consonant. ̯ consonantal vowel. ʃˢ variety of ʃ resembling s, etc.

Figure 5

On some occasions it is convenient to use a transcription in which some of the allophones are represented by specific symbols, or some of the phonemes are designated by the symbols for a more restricted set of categories. If, for example, the transcription were to be used in materials for teaching pronunciation, the difference between the aspirated and unaspirated allophones of /p/ might be represented by transcribing *pan* as [p^{h}an] and *span* as [span]; or the vowel phoneme in each of these words might be designated by the more specific symbol [æ], which represents a low front vowel of a certain type. A NARROW TRANSCRIPTION is one in which the symbols are more specific, either because allophones are differentiated, or because the phonetic quality of the sounds is shown more precisely. Allophonic transcriptions and symbols which are being used to designate a particular phonetic quality are usually put between square brackets; phonemic representations are put between slanting lines.

The most widely used set of symbols is that of the International Phonetic Association (IPA). The latest version of the IPA chart is shown in Figure 5. In general, the consonants have the same values as the corresponding letters in many European languages; and the vowel symbols have similar values to the corresponding letters in a language such as Italian.

EXPERIMENTAL PHONETICS

Experimental phonetics employs the methods of investigation commonly used in other disciplines such as physics, physiology and psychology, for measuring the physical and physiological dimensions of speech sounds and their perceptual characteristics. The sound spectrograph and speech synthesizers were mentioned in the section on acoustic phonetics. Other techniques include the use of x-rays, air pressure and air flow recording, palatography (a method of registering the contacts between the tongue and the roof of the mouth) and cinematography. All these techniques have been used for studying the actions of the vocal organs.

Much of the work in experimental phonetics has been directed towards obtaining more accurate descriptions of the sounds that characterize different languages. There have also been several studies aimed at determining the relative importance of different features in signaling contrasts between sounds. But experimental phoneticians are probably most concerned with trying to discover the central cerebral processes involved in speech.

One issue of this kind which has been extensively discussed is the so-called motor theory of speech perception. There is a great deal of evidence that the way in which people speak greatly influences their perception of what is said to them. For example, many foreigners (e.g. speakers of Spanish) cannot pronounce the different vowels in

words such as *ship* and *sheep*. These people also have difficulty in hearing the difference between these two vowels. But when they have learnt, by trial and error methods, to say them correctly, then they can easily hear the difference. Similarly, using synthetic speech stimuli it is possible to make a series of sounds which go by acoustically equidistant steps from [b] through [d] to [g]. When listeners hear these synthetic sounds they do not consider the steps between them to be auditorily equidistant. Those steps which correspond to the large articulatory movements between the consonants are heard as being much bigger than the equal size acoustic steps which do not correspond to articulatory movements which occur in the listener's speech. Facts such as these have led some phoneticians to believe that the perception of speech is structured more in motor (articulatory) terms, than in acoustic terms. Other phoneticians have claimed that the evidence does not really distinguish between these two possibilities, but demonstrates simply that the perception of speech is structured in terms of linguistic categories.

Another major problem is the size of the units that are involved in the perception of speech. Some authorities have claimed that a listener distinguishes between words by making a series of binary decisions concerning the features in each segment that he hears. Others hold that the listener takes in information in much larger temporal pieces, and perhaps processes speech in terms of units of at least the size of a syllable. All authorities agree on the importance of context. Speech conveys information in an extremely redundant way. Experiments have shown that a listener need attend to only a small proportion of the information presented to him in order to understand all that is being said.

A related problem is that of the temporal structure of speech production. There may be very little structure, and a speaker may simply time the movements of his vocal organs by allowing each gesture to run its course before starting on the next one. Alternatively, he may impose a hierarchical structure on the gestures by requiring, for instance, each major stress in a sentence to occur at some predetermined moment, and the articulatory movements to be speeded up or slowed down depending on the number of movements that have to occur before the major stress. There is some evidence in favor of this latter possibility as a result of experiments in which a speaker is asked to say a given phrase first slowly and then fast. When he is speaking at a rate which is twice as fast as some other rate, then the interval between the major stresses is about halved. But the duration of each segment is not halved. The consonants are only slightly reduced in length, whereas the vowels are considerably shortened. Some authorities have used the results of experiments of this kind to argue that the stress group is the major unit in the temporal organization or speech.

HISTORY OF PHONETICS

The earliest phoneticians were the Indian grammarians who wanted to preserve what they thought to be the correct pronunciation of Sanskrit. Their motives were religious, in that it was very important to them that their holy works should be pronounced in the traditional way. The works of Paṇini, the great Sanskrit scholar who lived about 2,300 years ago, are still highly regarded by grammarians.

None of the classical civilizations of the Mediterranean basin produced any phonetic descriptions of comparable importance. But it must be remembered that the Greeks were primarily responsible for the greatest phonetic invention of all time, the development of a writing system in which syllables are represented in terms of their component parts. All other writing systems suffer either from ambiguity in that many different syllables have to be written in the same way, or from requiring the reader to learn a very large number of different symbols. The realization that each vowel and each consonant could be conveniently represented by a separate symbol made it possible to write down any word that was said, using a comparatively small inventory of symbols.

In renaissance times Leonardo da Vinci made numerous observation on the physiology of speech. But apart from a few individual pieces of work which did not have much influence on the development of phonetic knowledge, there were no systematic descriptions of speech until the seventeenth century. Then grammarians such as John Wallis (1616 - 1703) included lengthy sections on speech in their work; and several publications by teachers of pronunciation and spelling reformers show that the method of production of most speech sounds was becoming generally understood.

It was not until the rise of linguistic science in the nineteenth century that the forerunners of modern phonetics can be clearly discerned. Following the earlier work of Sir Isaac Pitman and A.J. Ellis, in 1867 A. M. Bell published *Visible Speech.* This book proved to be a milestone in the history of phonetics, in that it provided a greatly improved set of categories for describing the sounds of any language. By using a very detailed notational system Bell and his co-workers (who included his son, Alexander Graham Bell, the inventor of the telephone) were able to write down small variations in speech sounds with an accuracy that had previously been impossible.

The emergence of phonetics as an independent field can be said to date from this time. The German scholar Eduard Sievers published his book on the physiology of speech sounds in 1876; and the *Handbook of Phonetics,* by the great English phonetician Henry Sweet, appeared in

the following year. Scholars in many other European countries were becoming interested in describing and comparing the sounds of languages. Paul Passy in France and Otto Jespersen in Denmark, joined with Bell, Sievers, and Sweet, and many others to form the International Phonetic Association in 1886.

The leading phonetician during most of the first half of the twentieth century was Daniel Jones, who started teaching in 1907, and retired as Professor of Phonetics, University College, London in 1949. He was president of the International Phonetic Association from 1950 till his death in 1967 at the age of 86. His numerous publications, particularly those on the pronunciation of the British accent known as RP (see above, Standards of Pronunciation), served as a model for phoneticians all over the world. Their influence can be seen in the phonetic aspects of the work of American linguists such as Leonard Bloomfield, Bernard Bloch, and many other leading figures in the period before the recent work of Chomsky and Halle.

The phonetic roots of Chomsky and Halle's work derive from the distinctive feature theories originated by the linguists in Prague headed by N. S. Trubetzkoy and Roman Jakobson. The culmination of Trubetzkoy's work was his *Grundzüge der Phonologie* which was published in 1939, the year after he died. Jakobson emigrated to the United States in 1941; his most complete statement of the theory of distinctive features, which was written in collaboration with Gunnar Fant and Morris Halle, appeared in 1951.

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