widths (damping constants) of the formants. A source located above the larynx in the vocal tract between cavities that have finite coupling to each other introduces zeros into the transfer function.

2.123 Shape of the Vocal Tract. The poles of the transfer function are primarily related to the geometrical configuration of the vocal tract and are independent of the source and its location. Calculations on the basis of x-ray data lead to substantial agreement between the poles and zeros of the predicted and measured spectra (3).

2.13 Neutral Position of the Vocal Tract

In the following, reference will be made to the neutral position of the vocal tract. This is the position of the vocal organs for producing a very open [æ] With respect to its acoustic results this articulatory position can best be approximated by a single tube closed at one end. As is well known, a tube of length L closed at one end resonates at frequencies where L is an odd multiple of one quarter wavelength. Since the average length of the vocal tract of males is about 17.5 cm, the resonances appear at approximately 500, 1500, 2500 cps. etc. The neutral position is of importance for predicting the effects on formant positions of variations in the over-all length of the vocal cavity of different individuals (3). It also serves as a reference point for the tenseness feature (cf. below 2.431).

2.14 Phoneme Boundaries

For practical purposes each phoneme can be represented by a quasi-stationary spectrum in which the transfer function is invariable with respect to time, except in the manner stated for transient effects (cf. 2.113). These transient effects, which are produced by rapid variations in the source function, may serve to delimit the individual phonemes in the chain. Rapid variations in the transfer function caused by swift changes in the position of the articulating organs also indicate the beginning or end (boundary) of a phoneme. Here, however, the minimum rate of change must be determined experimentally for each case. Rapid fluctuations in the over-all intensity of the speech wave provide an additional means for determining the location of a phoneme boundary.

2.2 FUNDAMENTAL SOURCE FEATURES

This class consists of two binary oppositions: vocalic vs. non-vocalic and consonantal vs. non-consonantal.

2.21 Vocalic vs. Non-Vocalic

Phonemes possessing the vocalic feature have a single periodic ("voice") source whose onset is not abrupt.

Usually, the first three vocalic formants for male voices are found below 3200 cps. The vocalic formants have small damping which expresses itself in the relatively narrow bandwidth of the formants. Because of the negative slope of the "voice" spectrum, the lower formants have greater intensity. But because of the ear's higher sensitivity to loudness in the region about 1-2 kc. it appears likely that in perception the effect of the declining spectrum tends to be equalized.

2.22 Consonantal vs. Non-Consonantal

Phonemes possessing the consonantal feature are acoustically characterized by the presence of zeros that affect the entire spectrum (cf. 2.441).

2.221 Vowels and Consonants. Vowels are phonemes possessing the vocalic feature and having no consonantal feature. A limited number of combinations of positions of the first three formants are significant for the identification of vowels. Information on the intensity level (other things being equal, vowels louder than other speech sounds), duration, rise and decay time of the sound furnish supplementary identifying criteria for vowels.

Consonants are phonemes possessing the consonantal feature and having no vocalic feature. Certain features of consonants are perceived most readily by the influence they exert over the formants of adjacent vowels, but even in the absence of any adjacent vowel, all the features of a consonant are perfectly recognizable; cf. the last phoneme in the English words whisk - whist - whisp or in the Russian words /l̦ˈift/ "elevator" - /f̦in̦ˈifț/ "enamel", /bˈukf/ "of letters" - /xarˈukf̦/ "standard" (see Fig. 10).

2.222 Liquids. The so-called liquids, i.e. the laterals (l-sounds) and the various intermittent r-sounds, have the vocalic as well as the consonantal feature: like vowels, the liquids have only a harmonic source; like consonants, they show significant zeros in their spectrum envelope. The formant structure of the liquids is basically similar to that of vowels. The configuration of their first three formants, however, usually differs from that of any vowel. In the beginning of a liquid we observe a very sudden downward shift of most formants which is due to the increased length of the resonator system in comparison with that of adjacent vowels. The over-all intensity of the liquids is considerably lower than that of the vowels.

2.223 Glides. The so-called glides (30), like the English h and the "glottal catch", are distinguished from the vowels in that they have either a non-harmonic source as in the case of [h] or a transient onset of the source as in [ʔ]. They are distinct from the consonants in that they have no significant zeros in their spectra.

2.224 Production. Vowels have no obstructive barrier along the median line of the mouth cavity, whereas consonants have a barrier sufficient to produce either complete occlusion or a turbulent noise source. Liquids are complex structures: they have a greater axial length-dimension in the direction of the air flow and they combine closure and aperture, either intermittently or by barring the median way and opening a lateral by-pass. Glides are produced by a stream of air passing through the glottis when it is narrowed or just after an abrupt opening following complete closure.

2.225 Perception. The vowels have far higher power than the consonants. As determined by Sacia and Beck, the average power for different English vowels is from 9 to 47 microwatts, while for consonants it ranges between 0.08 and 2.11 microwatts(4).

2.226 Occurrence. The distinction between vowels and consonants is universal. In America and Africa there are a few native languages without liquids. Many languages, e.g. Italian and Russian, have no glide phonemes.

The vowels figure predominantly as syllabics and, vice versa, the role of syllabics is assumed primarily by vowels. Most of the vocalic phonemes occur only as syllabics. A few others, being preponderantly syllabic, lose their syllabicity in some positions. For instance, English unstressed /i/ and /u/ become non-syllabic when adjacent to any other vowel (including the stressed /i/ and /u/); e.g. boy, day, geese, yes, yield (phonetically [j'i:ld] and phonemically /i'iild/), out, soul, shoe, well, wood (phonetically [w'ud] and phonemically /u'ud/) woo (phonetically [w'u:] and phonemically /u'uu/).

It is rare for non-syllabic vowels to be autonomous phonemes that may occur in the same positions as the corresponding syllabic phonemes; e.g. Russian /'ulii̯/ "hive" - /'ulii/ "hives".

Phonemes other than vowels occur for the most part only as non-syllabics. A few others (mostly liquids or nasal consonants), being preponderantly non-syllabic, acquire syllabicity in some positions. For instance, the Czech r and l become syllabic when preceded by a non-syllabic and not followed by a syllabic. Compare such dissyllables as škrtl [ʃkr̥tl̥] "scrapped", trval [tr̥val] "lasted" and monosyllables as rval [rval] "tore" and zlo [zlo] "evil". Syllabic liquids occasionally appear as autonomous phonemes capable of occurring in the same position as the corresponding non-syllabic phonemes; e.g. in Old Czech: dissyllabic brdu /br̥du/ "to the summit" - monosyllabic brdu /brdu/ "I stroll".

A set of rules, some of them universal, determine the pattern of the syllable. For instance, there is no known language where a syllable cannot begin with a consonant or terminate in a vowel, whereas there is a number of languages in which a syllable cannot begin with a vowel or terminate in a consonant. Thus, for a sequence of phonemes, the contrast of vocality and non-vocality is of primary importance, while the occurence of these opposites in one and the same position is much more restricted: cf. English wet /u'et/, yet /i'et/ with vet, set, net, etc., or he /h'ii/ with his /h'iz/, hit /h'it/ etc.).

2.3 SECONDARY CONSONANTAL SOURCE FEATURES

This class includes:

1) two types of features due to the primary source: a) envelope features, and b) the stridency feature,
2) the voicing feature due to a supplementary source.

2.31 Envelope Features

By the temporal envelope of sound intensity we mean the speech power averaged over about 0.02 seconds as a function of time. There are two basic types of envelope: smooth and rough. Phonemes with smooth envelopes have gradual onsets and decays and no abrupt changes in their temporal course. Phonemes with rough envelopes have abrupt variations of power in their temporal course. The latter can be subdivided into two groups depending upon whether or not there is sound after the abrupt variation in power.

Phonemes with smooth onsets are called continuants. They are opposed to interrupted (more exactly, discontinuous) phonemes, which have an abrupt onset. According to their decays, phonemes are divided into checked (with abrupt decays) and unchecked (with gradual decays.)

2.311 Interrupted vs. Continuant

2.3111 Stimulus. The abrupt onset distinguishes the interrupted consonants (stops) from the continuant consonants (constrictives). The onset of constrictives is gradual. The main characteristic of stops, on the contrary, is a sharp wave front preceded by a period of complete silence, for which, under certain conditions, a mere vibration of the vocal bands may be substituted. The spectrograms show here a sharp vertical line preceded either by a period of silence or a "voice bar" (1).

In English the abrupt onset of /p/ as in pill or of /b/ in bill is opposed to the smooth onset of /f/ as in fill or /v/ in vill. Similarly, /t/ as in till is opposed to /θ/ in thill and to /s/ in sill.

In the liquids it is not primarily the onset and decline that serve a distinctive purpose, but rather the interruption of the sound course. The continuant l-sound is opposed to the interrupted r-sound. There are two varieties of the latter: the flap with a single interruption and the trill with recurrent interruptions, which is much more common. Measurements of Czech trills show normally from two to three taps in the sound; in final position this may be reduced to a single tap, while the initial trill in emphasis has 4 to 5 taps. The rate of the taps is approximately 25 per second. There are languages, e.g. Mongolian, which have a considerably more rolled /r/ with a higher number of interruptions. Examples of the interruption feature in Czech liquids: /kora:l/ "coral" - /kola:r/ "Roman collar".