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THE PHYSICAL BASIS OF INTERVALLIC QUALITY AND ITS APPLICATION TO THE PROBLEM OF DISSONANCE

by

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A primary function of music theory is the formulation of basic concepts which will enable the student to understand more readily the essential principles of composition. Of the many problems that beset the theorist, few are more pressing than the enigma of "consonance" and "dissonance" — two words which are evidently the least understood of any in the vocabulary of music. Willi Apel notes that "no wholly satisfactory explanation and definition of consonance and dissonance has yet been found" [1, articles "Consonance," "Dissonance"], and Sir James Jeans refers to the consonance phenomenon as "one of the unsolved problems of music" [15, 156].

The writer does not propose that the line of thought pursued in this study be regarded as a panacea for the many controversies that have arisen from numerous attempts to account for the mystery of consonance and dissonance. It is hoped, nevertheless, that the observations presented here will be of value to the student who searches for more concrete channels of inquiry than are commonly offered.

The acute need for clarification of the dissonance problem is seen more clearly as we become aware of the lack of understanding on the part of various writers who have dealt with the subject in more or less detail. This is illustrated by the following commentaries, among which no general agreement exists as to the exact meaning of the terms "consonant" and "dissonant."

According to Walter Piston [21, 6-7], consonant intervals are "the perfect intervals and the major and minor thirds and sixths"; dissonant intervals are "the augmented and diminished intervals and the major and minor seconds, sevenths and ninths." As an exception, the perfect fourth is described as "dissonant when there is no tone below its lower tone," and "consonant when there is a third or perfect fifth below it." Piston then emphasizes that "the essential quality of dissonance is its sense of movement and not, as sometimes erroneously assumed, its degree of unpleasantness to the ear." Thus, in one breath, we are told that:

(1) dissonance is an inherent characteristic of certain intervals (the augmented and diminished intervals, major and minor seconds, sevenths and ninths);

(2) dissonance depends upon the response to intervallic function within a given musical situation (the "sense of movement");

(3) dissonance should not be regarded as unpleasant (although many listeners regard the atonal experiments of Arnold Schonberg — in which the "dissonant" intervals of seconds, sevenths, and tritones play a large role — as being particularly disagreeable);

(4) the dissonant quality of an interval may depend upon its position in a chord, and the same interval (e.g. perfect fourth) is therefore considered to be both consonant and dissonant!

Ernst Toch, on the other hand, tells us that "no sound, considered by itself and detached from any other context, can under any circumstances be other than neutral and meaningless... To divide any kind of sound, be it tones, intervals or harmonies, into one category of consonances per se — white sheep — and another one of dissonances per se — black sheep — is as absurd as it would be to divide the letters of the alphabet into consonances and dissonances" [29, 15]. Toch's view is generally supported by Helmholtz [13, 227-8], who says that "from the most perfect consonance to the most decided dissonance there is a continuous series of degrees, of combinations of sound, which continually increase in roughness, so that there cannot be any sharp line drawn between consonance and dissonance, and the distinction would therefore seem to be merely arbitrary ... the decision does not depend, then, on the nature of the intervals themselves but on the construction of the whole tonal system." But Helmholtz also notes that "any relation of pitch which cannot be expressed in small numbers is dissonant" [13, 331], thus completely reversing his earlier statement!

Musical consonance and dissonance are defined by Norman Cazden [7, 161] as "qualitative responses to relations among harmonic aggregates of tones within the frame of reference of a particular musical culture," and G. Révész also refers to the consonance-dissonance phenomenon as the result of "esthetic evaluation" [24, 89]. But E. G. Bugg observes [5, 17] that it is "a mistake to attempt to make the history of the art of music the basis for a scientific explanation of consonance"; and Apel tells us that "every interval contained in the major (or minor) triad and its inversions is a consonance, the other intervals are dissonances" [1, articles "Consonance," "Dissonance"], in spite of Toch's insistence [29, 12] that "in the light of light there are countless shades of shade"!

Among the theorists who adhere to the concept that an isolated interval per se may be categorized as consonant or dissonant, there are many who classify the consonances as perfect or imperfect (or primary and secondary). J. J. Fux, well-known 18th-century theorist and composer, refers to the unison, fifth, and octave as perfect, the sixth and third as imperfect; he then calls the second, fourth, diminished fifth, tritone, and seventh dissonances [11, 15]. A similar approach is used by W. J. Mitchell although, as is the case with many theorists, the Fux terminology is no longer adhered to, and the "primary" consonances now include the unison, octave, fifth, and major third. The sixths and minor third remain "secondary," while the fourth joins the secondary consonance category [19, 32]. Goetschius, however, does not hesitate to classify the unison, octave, and perfect fifth as "secondary" consonances [12, 20]!

Again it should be evident that there is no general agreement as to the exact musical meaning of the words "consonant" and "dissonant." The foregoing quotes, in spite of many discrepancies and contradictions, are useful in that they clearly expose the nature of the dilemma. Consonance-dissonance, to some (Bugg, Apel, Fux, etc.) is seen to mean the intrinsic, irrevocable characteristics of a particular interval in isolation; while to others the phenomenon is largely a qualitative response dependent upon context (Toch, Cazden, etc.). It seems obvious, therefore, that both consonance and dissonance are commonly conceived as dualistic phenomena — i.e. they are both defined according to the following classifications:

(1) as predetermined, categorical evaluations of isolated intervallic sonorities (the non-functional approach);

(2) as qualitative responses to contextual intervallic relations (the functional approach).

Theorists who favor the non-functional classification of intervals as consonant or dissonant, regardless of context, usually make their judgements on the basis of number ratios, beating phenomena, or fusion. These characteristics, in turn, are assumed to account for various degrees of roughness-smoothness, or pleasantness-unpleasantness. Pythagoras proposed that sounds made by strings whose lengths are to each other as 1:2: 3:4, are more pleasant when heard together than sounds from strings whose relative lengths are expressed by larger numbers [23, 69]; and Jean Philippe Rameau observed [22, 5] that "the order of the origin and perfection of consonant intervals is determined by the order of the numbers" (in the natural harmonic series) — i.e. the smaller the number ratios, the greater the consonance. Many acousticans of the 20th century still adhere to the same ancient premises, in spite of the fact that the equally tempered fifth, which cannot be distinguished by ear from the Pythagorean pure fifth, is approximately equivalent to the ratio 295:442 [31, 7] — hardly a small-number relationship. F. R. Watson, for example, tells us [30, 107] that "two pure tones are harmonious and pleasing to the ear if the ratio of their frequencies is made up of small numbers."

Helmholtz, in addition to his other theories of consonance, suggests that intervals are consonant if no "disturbing" beats are produced by the two tones or their harmonics [13, 186ff], and then arranges the various intervals in "order of smoothness" [13, 193]. Otto Ortmann, however, states that "quality is a psychological reaction and has no independent physical component" [20, 3].

Intervallic classification according to the theory of "fusion" is chiefly the result of investigations conducted by Carl Stumpf [28], who measured the consonance of intervals according to their tendency (to the trained ear) to fuse together as a tonal unit (klang). Stumpf, in direct contrast to Ortmann, did not feel that the smoothness, or blending quality, of certain intervals was explainable on psychological grounds. It was his opinion that "the cause of fusion is a physiological one ... the nature of the situation indicates that it is an aspect of feeling, a relationship inherent in the simultaneous tone-qualities, and independent of individual experience. The relationships of feeling, like feelings themselves, are not based on underlying psychological causes but only on physical ones" [28, 2:211]. Révész, however, maintains that the blending quality of the octave, for example, is a result of "phenomenological similarity," not of fusion [24, 61].

The result of these many irreconcilable viewpoints is, of necessity, complete and thorough confusion. The issue, however, remains clear. Are we to regard consonance and dissonance as *non-functional* intervallic sonorities with varying degrees of "roughness" or "smoothness," or do we consider them to be qualitative responses to *functional* musical situations? To continue the dualistic description of consonant and dissonant intervals can hardly contribute to the growth of music theory as a practical science. *Consonance and dissonance should not be used to describe both functional and non-functional situations.*

Surely, it borders on the ridiculous to tell a student that isolated intervals may be classified a priori as consonances and dissonances, and then to declare that a dissonance is really nothing but an interval which must "be followed by another harmony, without which the effect would be unsatisfactory and incomplete" [25, 16]. According to the rule just stated, any interval might be "dissonant" in function if it seemed to require resolution and, if such be the case, why bother to categorically label every interval as consonant or dissonant? Imagine the student's confusion when he is taught [25, 17; 20, 6] that the interval in Ex. 1 is consonant, but that the interval in Ex. 2 is dissonant!

Example 1.

Example 2.

The usual explanation, of course, is that the augmented fifth has a tendency to resolve upward, and that this "leaning" towards resolution conveys an impression of incompleteness (and consequently, dissonance) to the ear. Is it not equally logical, however, to assume that the minor sixth also could have a tendency to resolve *downward* (e.g. IV^6_4 — I in c minor), and that such a tendency toward resolution would demand that it, too, be classified as dissonant? The same reasoning applies to all intervals, since any interval may be spelled enharmonically.

Semantic dualism of this nature can only produce connotative contradictions which add fuel to the controversy and offer little in the way of a solution. It is no longer possible, for example, to appreciate the meaning of music critics when they make statements similar to the following:

> Herr Von Einem opens with a movement marked Maestoso. It begins with a series of brass fanfares of dissonant nature contrasted with string passages of consonant nature.[1]

1. From an article by Harold Rogers (*Christian Science Monitor*, Oct. 12, 1957) on the *Symphonic Scenes for Orchestra*, Opus 22, by Gottfried von Einem.

Does the writer mean that the brass fanfares consisted of many so-called "dissonant" intervals of seconds, sevenths, and tritones which disturbed him because of their roughness, or is he merely implying that the passages for brass were loud and strident in contrast to the lower decibel output of the strings? Or, on the other hand, was he perhaps aware of certain disturbing contextual intervallic relationships in the brass which — due to imbalance or obviously inappropriate distribution — caused a disturbing psychological response as opposed to the perhaps logical intervallic texture of the string passages? Because of the present confusion in terminology, we actually have no way of knowing whether the critic was describing a qualitative response to contrasting functional intervallic situations, or whether he was simply referring to the apparent roughness (or lack of it) of isolated chord-structures. We can not know for sure since the words "consonant" and "dissonant" have no generally accepted meaning.

The problem, therefore, is obviously one of semantics, and the solution does not hinge upon the question as to which isolated intervals shall be termed "consonant" or "dissonant," but upon the decision as to the exact meaning of the words themselves. We may regard consonance and dissonance as words which describe <u>non-functional</u>, individual intervallic structures, or as words which express the listener's response to <u>functional</u> musical situations. But the non-functional approach can hardly meet with any more success in the future than it has in the last 2500 years, since any interval can be made to sound "out-of-place" or "off-balance" by creating an intervallic or rhythmic texture which deliberately exposes the interval or chord in an awkward manner. Among the many available illustrations, the following by Ernst Toch [29, 12] is particularly effective:

Example 3.

Observe how the <u>dissonant</u> major triad in m. 4 finds no repose in itself, but <u>demands resolution</u> into the following 7th chord! This in spite of the fact that the C-major triad is made up entirely of so-called "consonant" intervals, and that physicists tell us "to learn whether a triad is consonant we examine the intervals that form the triad" [16, 53].

Webster defines musical consonance as "a combination of tones giving a sense of repose, not requiring resolution" and the adjective, "consonant," is shown to mean "consistent" or "compatible." These terms appear to be quite adequate for the description of qualitative responses to functional musical situations and, in view of the obviously irreconcilable contradictions of the non-functional approach, it would seem advisable to use the expressions "consonant" or "dissonant" only when referring to an individual's psychological response to contextual situations.

Studies in music theory should no longer use the terms "consonance" or "dissonance" when describing the quality of isolated, non-functional intervals. Both words are extremely useful when confined to functional situations, but their non-functional use has contributed little or nothing to the clarification of theoretical problems. The above principles, therefore, will be adhered to throughout the remainder of this study, and consonance or dissonance, as such, will not be used in any other context than the following definitions suggest:

Consonance — a functional combination of tones which stimulates — within the individual — a sense of repose, relative stability, and equilibrium.

Dissonance — a functional combination of tones which stimulates — within the individual — a sense of stress, relative instability, and imbalance.

To discontinue the use of "consonance" and "dissonance" for the description of static intervallic sonorities, however, creates an immediate need for new terminology. If isolated intervals are to be measured no longer in terms of a fictitious "consonant" or "dissonant" evaluation, how then shall we describe them?

It is quite obvious that all intervals, regardless of their musical application, do not sound alike, and some method of description must be devised which adapts itself equally well to functional and non-functional situations. As we have noted, the irreconcilable confusion concerning the meaning of consonance and dissonance makes the continued use of these words extremely impractical when applied to non-functional sonorities, but this does not mean that intervals no longer may be categorically classified as individual entities. The real need is for an indisputable scale of measurement which will aid in the evaluation of the various intervals according to their sonorous properties. Such a scale would provide a basis for the determination of potential stability-instability, simplicity-complexity patterns that occur in the evolution of vertical, diagonal, and horizontal intervallic areas. Before exploring the problem of simplicity and/or complexity further, however, let us pause for a moment in our probing for a more concrete description of intervallic sonority to consider the nature of the medium through which tones and, consequently, intervals are perceived.

The planet earth is surrounded by a gaseous envelope which exerts a pressure of about 14.7 lbs. per square inch (at sea-level) upon all exposed material objects, and it is this invisible, odorless, and tasteless mixture which transmits the pressure changes that produce the sensation of hearing in the human ear [4, 2]. These pressure changes — the result of molecular compression variations — are brought about by the agitated motion of material objects with sufficient impetus to cause a displacement of air particles [27, 455]. An object at rest,[2]

2. Properly speaking, no air particle is literally at "rest," since gaseous molecules are constantly in motion (Kinetic Theory). "State of

Diagram 1. Alternate condensation (compression) and rarefaction (decompression) of a single "stream" of air particles.

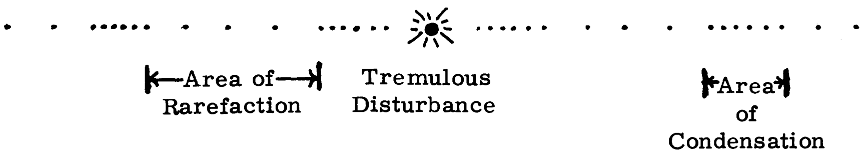


Diagram 2.

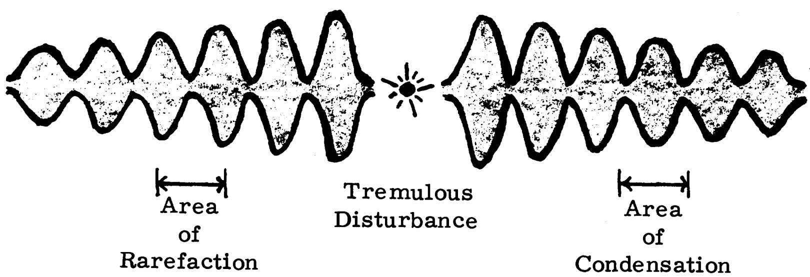
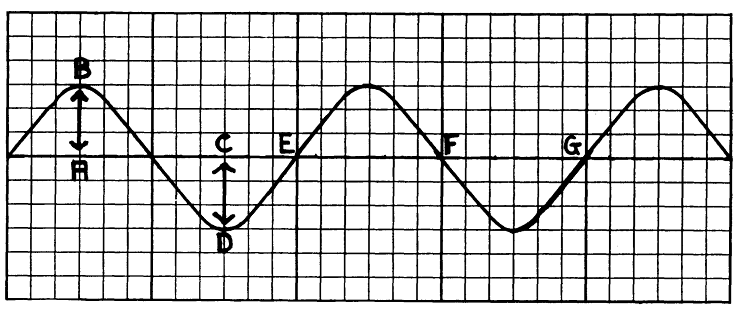


Diagram 3.



of course, will not disturb the air mass around it, but if force is applied so as to cause the object to change its spatial position, the resulting movement will act against the surrounding air particles and effect a compression of these particles. Such action produces an opposite reaction which continues until the original disturbance has dissipated, and this alternation of molecular condensation and rarefaction constitutes the phenomenon known as "vibration." Air vibrations occurring at a rate of about 16 to 40 times per second, or faster, stimulate the hearing response termed "sound."

To force a material body from a position of rest implies the tendency of this body to return to its original locus due to the pull of gravity. Also, the impulse of the disturbance gives the moving object momentum, so that it tends to pass beyond its starting position. Thus, the most important principles [4, 3] underlying vibration are:

(a) the tendency of a body to return toward its rest position if it be displaced therefrom (elasticity), and

(b) its tendency to overshoot the rest position, becoming displaced in the other direction (momentum).

In other words, once an air particle is set in motion, elasticity and momentum tend to keep it in motion until inertia causes it to return to rest. The same reasoning may be assumed to apply when a large number of particles are displaced and, of course, any vibratory pulsation in the atmosphere instantaneously involves millions of air molecules. To describe this phenomenon visually is well-nigh impossible, but the following diagrams may prove helpful. Each dot in Diagram 1 (p. 179) theoretically represents an air molecule, although a molecule of air is not only invisible, but also infinitesimal.

This type of particle pulsation is termed "longitudinal displacement" [16, 14]. It is necessary, however, that we try to visualize the pulsation pattern as simultaneously extending in all directions from the source of atmospheric disturbance. A "cross-section" of this contracting-expanding, accordion-like activity might look something like Diagram 2 (p. 179).

This type of particle pulsation is termed "transverse displacement" [17, 14], and has become the more popular method for representation of particle displacement because of its visual convenience. Again, however, it is necessary to imagine the process as a simultaneous projection in all directions. The continuum of transverse motion shown in Diagram 2 is quite similar to the form of periodic motion known as "simple harmonic motion," and the latter may be illustrated by a "simple harmonic curve" (Diagram 3, p. 179).

A simple harmonic curve is elementary, regular, symmetrical, and is an instantaneous graphic representation of the condition of motion in a simple wave [15, 12] — i.e. the distances AB or CD illustrate amplitude or intensity (the amount of particle displacement), and the distances EF or EG illustrate consecutive periods in time (the fre-

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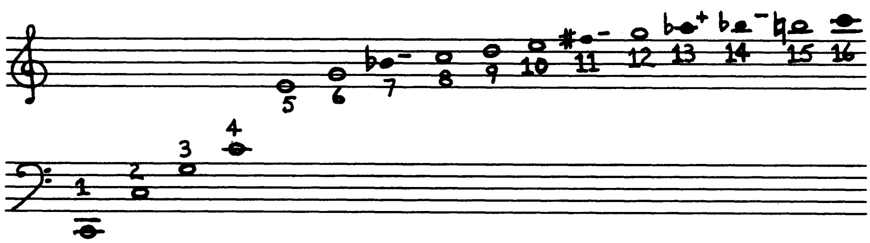
equilibrium" would be more appropriate, but the former term is employed in acquiesence to common usage.

quency of particle displacement). In other words, the simple curve in Diagram 3 represents "molecular displacement in time"; and since a vibration is considered complete when it returns to its starting point, the distance EG is termed a "phase." Thus, when we say a tone has a frequency of 440 cycles-per-second, we mean that a given pressure-wave goes through 440 complete phases of vibration in one second.

The factors of "amplitude" and "periodicity," as represented by a simple harmonic curve, are particularly important to this inquiry. But in the study of intervals we are also concerned with amplitude-periodicity relations between two or more tones, and it is necessary, therefore, to comment briefly upon the source of interval ratios.

Air columns of relatively constant density, or strings of relatively constant tension, will produce composite vibration waves which contain a fundamental, predominating tone, as well as other tones of less intensity known as "overtones." These overtones, partials, or harmonics are the instantaneous result of an infinite series of vibratory pulsations which are present with the fundamental tone. The lesser vibrations, although not easily heard as individual pitch-units, are always present with the fundamental and stand in fixed mathematical ratios to the frequency of the fundamental. Assuming the tone C to be a given fundamental, Ex. 4 illustrates the well known overtone complex[3] that sounds simultaneously with the fundamental tone.

Example 4. First 16 partials of the tone C.



By referring to the harmonic series it is seen that ratios for all of the intervals are readily available. The interval of the octave, for example, is formed by tones related as 1:2, and the fifth is seen to be formed by the ratio of 2:3. Ratios for the major third (4:5), minor third (5:6), and major second (8:9) — and for any interval — are similarly in evidence. Furthermore, since the ratio for the perfect fifth, for example, is 2:3, we know also that 200 cycles-per-second against 300 cycles will sound like a perfect fifth; 300 against 400, like a perfect fourth, and so on.

Having acquired a "speaking acquaintance" with the nature of sound and the source of interval ratios, let us return to the problem of adequate terminology to be employed in the description of static (i.e. isolated) intervallic sonorities. It is important, however, to understand clearly that the <u>various graphic representations of wave amplitudes and periodicities are no more than rough illustrations of some of</u>

3. Black notes indicate tones that can be identified only approximately in our present day system of equal temperament. Plus and minus signs indicate whether the tone is sharp or flat.

the more easily perceived characteristics of vibrational phenomena.

The configurational behavior of air particles in vibratory motion is extremely complex and, in addition, relatively little is known about the way in which the ear really hears. The best writers on sound and hearing (Fletcher, Stevens-Davis, Jones, etc.) have continually warned their readers against over-simplification in the analysis of acoustical situations. Pause for a moment to reflect upon the incredible number of vibrational phenomena that surround the ear during a symphonic concert. Pressure waves are transmitted from many different kinds of instruments across a large hall to the ears of listeners seated at various distances from the orchestra. These waves are subjected to reflection (by walls, floor, ceiling), absorption (by drapes, carpets, clothes of individual persons), interference (as the result of superposition of individual wave trains), and set up sympathetic vibrations within the floor, seats, walls and ceiling of the hall. In addition, the orchestra itself is actually composed of a mixture of tunings [3, 200]; in that the piano and harp are tuned in equal temperament, the strings tend toward Pythagorean intonation, and the brass plays essentially in just intonation. The listener, however, adjusts himself almost immediately to the surrounding cacophony, and accepts the result as "a good performance"!

Situations of this kind point up the marvelous ability of the ear to find a mean between extremes. Compare, for example, the aural response to vibrato, an effect produced by rapidly fluctuating between the adjacent pitches above and below a given fundamental tone. The vibrato actually produces a whole family of tones of different pitch and intensity [17, 215], and the apparent richness of vibrato is due to the presence of these tones on either side of the central pitch [4, 24]. Oddly enough, due to the ear's power of mean discrimination, vibrato does not obscure the pitch of the fundamental tone. If several tones of nearly the same frequency (e.g. 600, 604, 608, 612, 616 c.p.s.) and intensity are sounded together, the resulting tone will be judged by the ear as having a pitch which is the approximate mean of the highest and lowest extremes [4, 24]. This fact and other similar phenomena have led the writer to believe that the mean perception of pitch is the outstanding feature of the ear's ability to discriminate between manifold acoustical events.

Other characteristics of tone such as intensity, duration, quality, volume, and brightness are important; but these factors are of little consequence if the listener is unable to perceive pitch. It seems safe to assume that we are not concerned as much with how loud a tone is sounded, or how long it is sustained by a single- or double-reed instrument, as we are with its location on the musical staff. And, fortunately, the first significant musical information that the ear transmits is evidently that of pitch-identity; other factors seem to be a secondary response.

Fletcher tells us [10, 61] that the subjective phenomenon which we identify as pitch is the result of the objective stimulus, frequency. In other words, when we identify pitch we are responding primarily to an event or combination of events in the time-domain, because frequency is the result of the periodicity of wave phases. Now an isolated interval is formed by superimposing one wave-train upon another, and the result of this superposition is what we identify as an octave, fifth, or fourth, etc. Thus, we are again faced with the necessity of deciding which aspect of the interval phenomenon is the most easily perceived by the ear and, due to its relatively constant nature, might therefore be used as a criterion for non-functional, descriptive terminology.

As noted earlier, the equal-tempered fifth cannot ordinarily be distinguished by ear from the Pythogarean fifth and, although the frequency ratio of the former is around 295:442, the aural response seems to be identical to the one stimulated by the ratio 2:3. It is evident, therefore, that the ear is able to accept the 295:442 ratio as a mean approximation of the true 2:3 ratio. If such were not the case, the practical performance of music would be impossible, since no instrument without a set tuning (e.g. keyboard instruments) can be relied upon to produce intervals which are perfectly adjusted according to the ratios of natural (just) intonation. Realistic theorists have known for years that tuning is actually a system of compromise within a particular frame of reference [3, 197-9].

The above should not be construed as an acceptance of the "small-number theory" of consonance. To demonstrate that the ear can perceive a mean approximation in small numbers between slightly mistuned intervals does not give us license to proclaim the consonance or dissonance of such intervals. To discover that two tones are related as 3:4 or 221:295, or any other ratio, does not warrant their being labeled as inherently consonant, since any interval can be forced into a situation of imbalance and thus become dissonant.

The real importance of the foregoing, to this inquiry, is that the ear's power of mean discrimination in the time-domain is as acute when perceiving intervallic relations as when identifying individual tones. It is the writer's opinion, therefore, that <u>when we identify interval we are responding primarily to an event or combination of events in the time-domain, because interval is essentially the result of superimposed periodicities of wave phases</u>.

Let us now examine the phenomenon of wave superposition more closely. Assume that a wave of 300 c.p.s. (wave "A") is to be superimposed against a wave of 200 c.p.s. (wave "B"). The ratio between the two frequencies will be 300:200 or, more simply, 3:2, and the auditory response will be that of a perfect fifth. At the same time, a new wave (resultant "R") is produced as the result of interference between the two superimposed periodicities. This is illustrated in Diagram 4 (p. 184) by using the simpler of the above ratios, i.e. 3:2 rather than 300:200.

Wave A goes through three complete cycles every second, and wave B goes through two complete cycles every second. A total time duration of two seconds is shown in this example so that the repetitive shape of the resultant wave can be clearly seen. It is obvious that the configurations of the resultant wave are no different during the second time-period (between one and two seconds) than the first, nor will its essential periodic shape change during subsequent time-periods.

Further, it is seen that, during the two seconds of time, the resultant wave intersects first wave B, then wave A in an unchanging, alternating pattern. These points of intersection are indicated by arrows, and the numbers between the arrows show the fractional parts

Diagram 4.

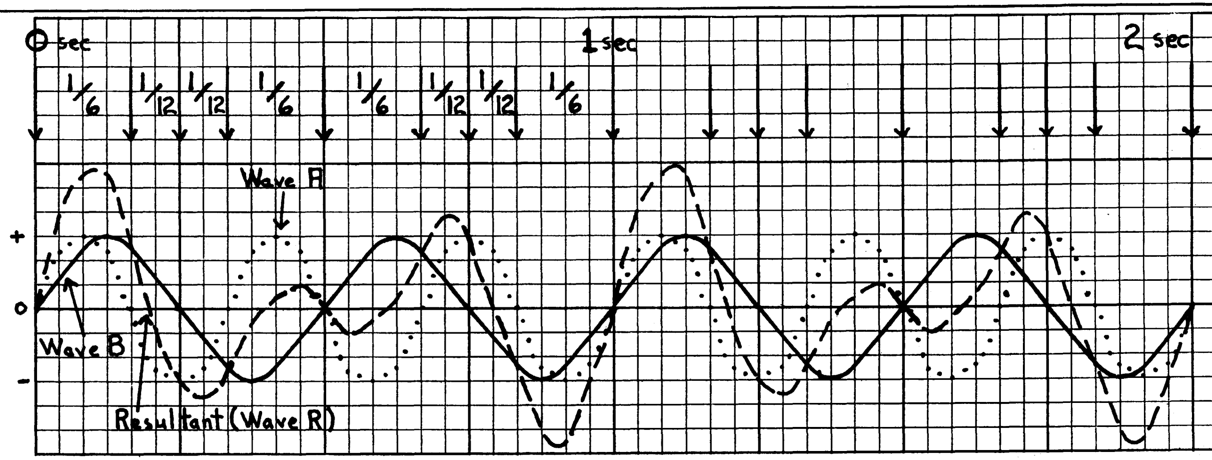
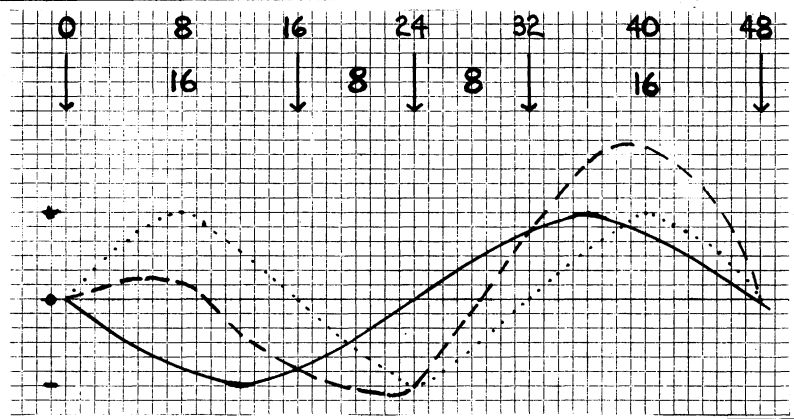


Diagram 5.



of a second which elapse between intersection points. In other words, between the first and second points of intersection there are 4 graph-units, and between the second and third points of intersection there are 2 graph-units — i.e. 1/6 and 1/12 respectively of the total number of graph-units representing one second in time. There are also 2 graph-units between the third and fourth points of intersection and 4 units between the fourth and fifth points — i.e. 1/12 and 1/6 respectively of the total number of graph-units representing one second.

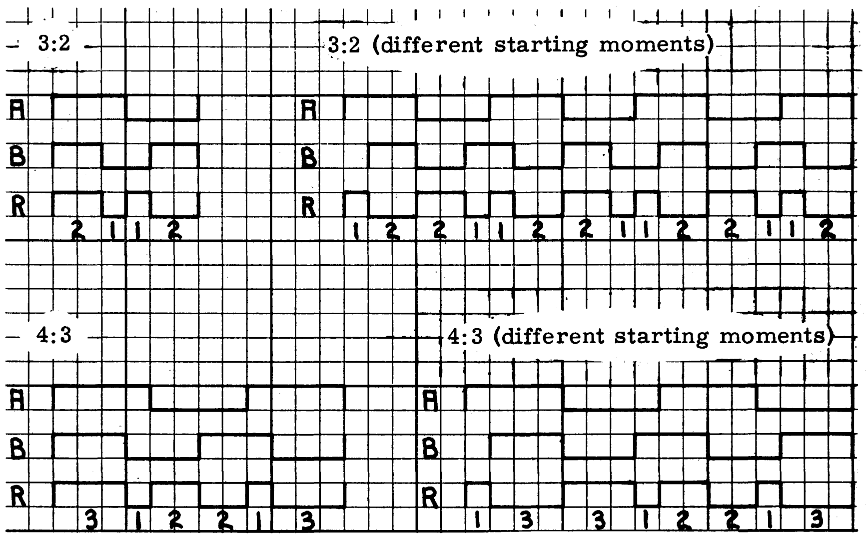
Thus, the fractional sequence of 1/6, 1/12, 1/12, 1/6 is equivalent to 4, 2, 2, 4 graph units in continual repetition or, more simply, to the proportion 2:1:1:2. The general conclusion to be drawn from these observations is that the resultant wave of 3:2 alternately "intersects" the original generating waves at temporal points which are proportionately related to one another as 2:1:1:2. The importance of these points of "intersection" is more clearly seen upon further examination of the superposition phenomenon.

Diagram 4 provides a visual approximation of what happens roughly in terms of amplitude and periodicity when two waves of different frequency are superimposed. The most obvious feature of this superposition process is that waves A and B are relatively coincident in phase at some points and almost opposite in phase at other points. They are either "adding" to one another or "subtracting" one from the other — i.e. there is a succession of reinforcements and cancellations of amplitudes. But, in contrast to the additive-subtractive aspects of superposition, there are certain points in time where no reinforcement or cancellation takes place. Such moments occur when either of the two original waves equals "zero" — i.e. when A or B crosses the zero-abscissa — and, therefore, can neither be adding to nor subtracting from the other wave.

A resultant wave provides visual evidence of these moments. The second arrow in Diagram 4, by way of illustration, indicates that point at which wave R first intersects wave B. Note that wave A, at that same moment, is just crossing the zero-abscissa and, therefore, is neither "plus" nor "minus," neither reinforcing nor cancelling. The third arrow indicates the point at which wave R first intersects A. Note that wave B, at that same moment, is also just crossing the zero-abscissa and, therefore, is neither adding to nor subtracting from wave A. The remaining arrows indicate similar time-moments. These moments, occurring in regular sequence at points periodically related as 2:1:1:2, represent fluctuations in pressure which are directly related to changes in molecular mass — i.e. any pressure fluctuation involves a displacement of air particles which, in turn, produces condensation or rarefaction in certain areas. The pressure fluctuations extend throughout the perceivable volumic area (space occupied) of the interval, and constitute patterns of variable density throughout the volumic area.

Density, as a physical phenomenon, is mass per unit-area — e.g. a cc. of wood is considered more dense than a cc. of air because the mass of the former per unit-area is greater than the mass of the latter. Pressure changes are directly related to variations in density, since fluctuations of pressure are changes in particle mass per unit-area. The writer submits, therefore, that the predominant relationship between frequencies of different periodicity is found in the time-domain;

Diagram 6.


3:2
3:2 (different starting moments)
A
B
R
2 1 1 2
1 2 2 1 1 2 2 1 1 2 2 1 1 2
4:3
4:3 (different starting moments)
3 1 2 2 1 3
1 3 3 1 2 2 1 3

and that this relationship is perceived as minute, rapid fluctuations of pressure, measurable in terms of time-moments resulting from waves in superposition. This phenomenon, in its broadest sense, will be regarded as intervallic density[4] — i.e. the amount of particle activity in a perceivable unit-area.

The process described in Diagram 4 may be illustrated equally well, and more simply, by utilizing only the essential features of the interference pattern. Observe that the regular sequence of time-moments periodically related as 2:1:1:2 occurs four times in two seconds. It is evident, therefore, that all subsequent patterns of pressure change are but repetitions of the events taking place in the first half-second of time. The same procedure for example, is duplicated in Diagram 5 (p. 184) by subdividing a distance of 48 graph units along the zero-abscissa into three equal wave sections (dotted line), and superimposing this tripartite division against a bifold subdivision of the same 48 units — in other words, 3:2.

The resultant wave intersects the generating waves at the points indicated by arrows, and the order of graph-units between the points of intersection is seen to follow the sequence 16, 8, 8, 16 or, as before, 2, 1, 1, 2. The most convenient visual method, however, is found in the use of so-called "square" waves, by means of which any resultant of interference may be calculated easily. Diagram 6 (p. 186) shows the result of superimposing three graph-units (wave A) against two (wave B) and, also, four units (wave A) against three (wave B). The resultant (R), in both cases, is identical to the proportions resulting from superimposed sine waves of 300 cycles against 200 cycles, and 400 cycles against 300 cycles respectively.

It is interesting to note that the starting moment of the two wave trains does not affect the overall sequence of periodic events. Even though one starts later than another, it will soon fall into phase. Interested readers may experiment with sine waves in the same manner by having either wave start 1, 2, 3, or any number of cycles before or after the other. It will be found that the two waves synchronize quickly regardless of the starting moments. By using square waves, the foregoing principles may be applied also to specific changes in amplitude level. Diagrams 4, 5, and 6 represent visually the points in time where no reinforcement or cancellation of amplitude takes place with superimposed waves whose frequency ratios are related as 3:2 or 4:3. The changes in amplitude level between these time-moments can be illustrated roughly by assigning a positive-number value to each vertical graph-unit. Horizontal graph-units are used, as before, to indicate temporal-durational periodicities.

Suppose, for example, that each vertical graph-unit, or "block," has the value of "1." Diagram 7 (p. 188) shows the resultant amplitude changes between two square waves whose periodicities are related as 3:2. Note that the resultant configuration remains at +2 for two time-units before dropping to zero for one time-unit. After dropping to -2 for one more time-unit, the amplitude pattern returns to zero for two

4. Not to be confused with Joseph Schillinger's use of the word, which he employs to describe an indefinite sense of "fulness" [26, 700]. Density, in this study, pertains to a mensurable, objective phenomenon.

Diagram 7.

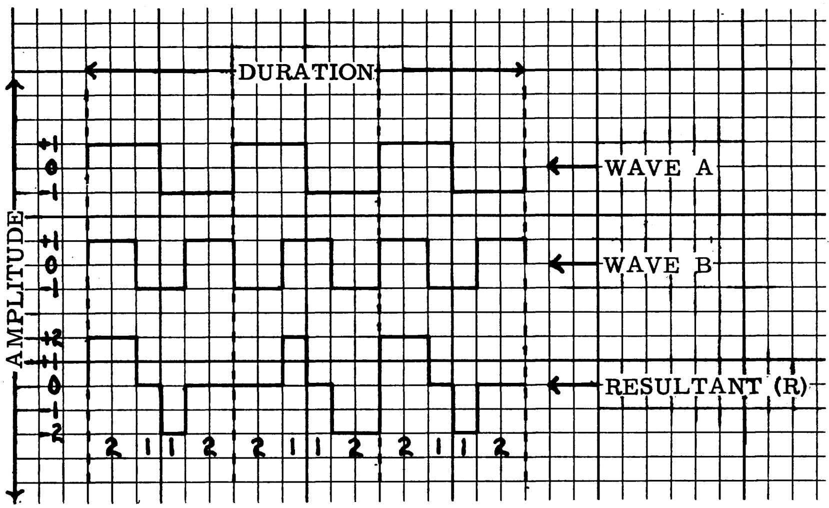


Diagram 8.

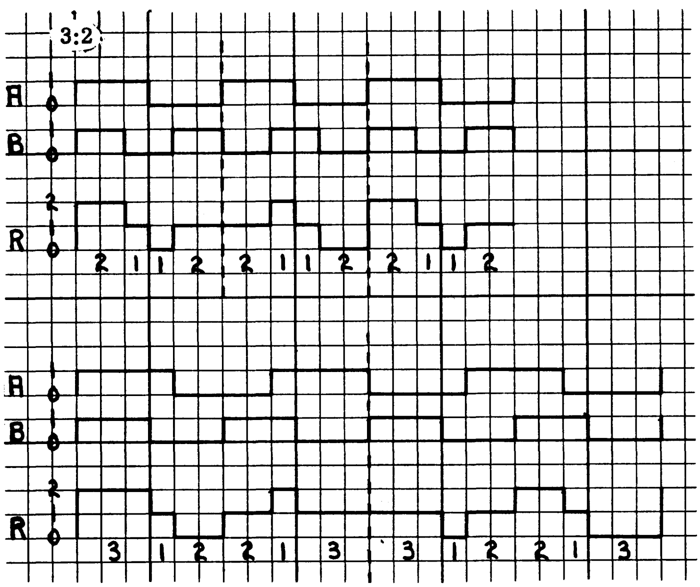


Diagram 9.

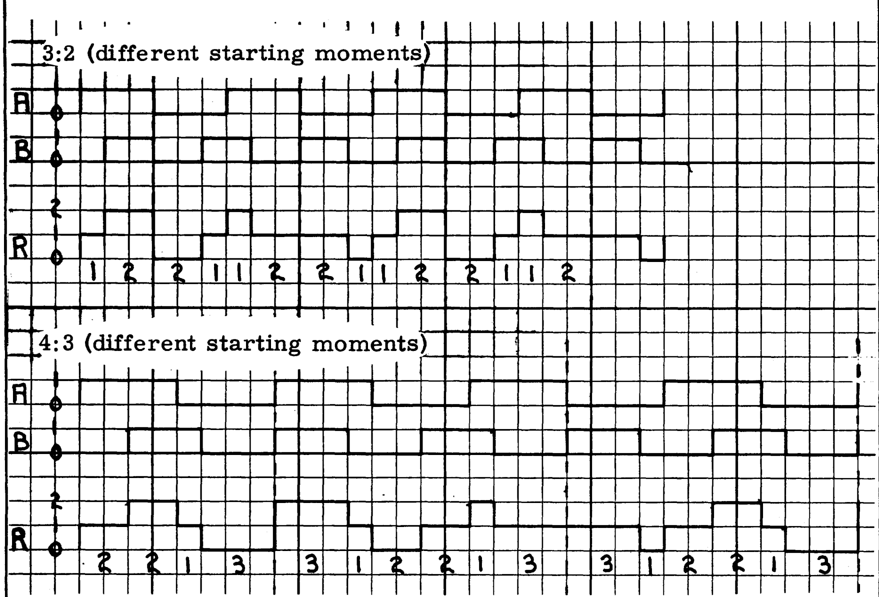
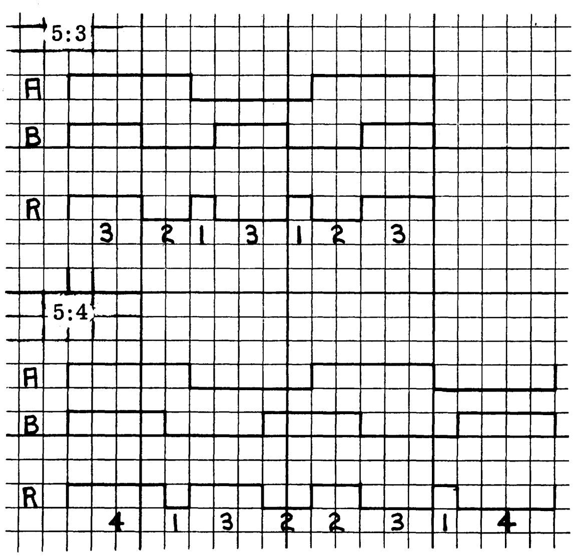


Diagram 10.



time-units. From this point on the resultant repeats itself continuously (each repetition is bracketed by dotted lines).

The same results may be obtained more simply as in Diagram 8 (p. 188), where the durational changes in amplitude level are shown for 3:2 and 4:3. Starting moments of the two wave trains will not affect the over-all amplitude change patterns. As illustrated in Diagram 9, the waves begin to synchronize almost immediately.

The foregoing examples reveal, therefore, that the additive-subtractive aspects of wave superposition yield a pattern of pressure fluctuation that is directly related to the numerical periodicities of the superimposed waves. A wave of 300 c.p.s. against a wave of 200 c.p.s. (i.e. 3:2) will produce changes in amplitude level. The approximate time-moments between these amplitude changes are periodically related as 2:1:1:2, and may be described as durational changes in amplitude level. A wave of 400 c.p.s. against a wave of 300 c.p.s. (i.e. 4:3) will produce changes in amplitude level, the time-moments between which are periodically related as 3:1:2:2:1:3 (Diagrams 6, 8). Such durational changes in amplitude (intensity) level are directly proportional to the amount of particle activity in a perceivable intervallic area, and are regarded as variations in density.

An interval resulting from 300 c.p.s. against 200 c.p.s. is consequently less "dense" than one resulting from 400 c.p.s. against 300 c.p.s., because the former excites less activity than the latter. Pressure fluctuations periodically related as 2:1:1:2 are less turbulent than fluctuations periodically related as 3:1:2:2:1:3 — i.e. the total air mass (volumic area) is less "disturbed" in the case of the former.

By using the foregoing procedures (especially the square-wave method, for simplicity), the relative amount of particle activity resulting from superposition — i.e. density — can be determined for any interval. Relative density for the major sixth (5:3) and major third (5:4) is computed in Diagram 10 (p. 189). The method is identical with that shown in Diagram 6.

We are now ready to evolve a complete scale of absolute sonority in terms of density ratings. The density of each of the intervals given in Table I (p. 191) was determined according to the method described above. Interval ratios are taken from the natural harmonic series.

Special mention should be made of the so-called "tritone" which derives its name from the fact that it contains three "whole-tones." This interval, proscribed in early polyphonic music as diabolus in musica (the devil in music), remains even today a ferment among the family of intervals due to its peculiar characteristics, the following being the most outstanding:

(1) the intervallic ratio for the tritone does not occur in the first sixteen partials of the harmonic series as do the other interval ratios. The proportions 5:7 or 7:10, contrary to popular opinion [14, 81-2], do not evoke the interval response we know as the "tritone effect." These proportions, when sounded in pure tone by oscillators, produce an effect which is unlike any interval among the first sixteen harmonics, but observers who have actually heard such an experiment[5] in the laboratory are aware that the aural response is not

5. Six trained musicians were tested (February, 1956) by the

TABLE I

DENSITY SCALE

Interval	Periodic Complexity Patterns from Wave Superposition
(1:1) Unison	1
(1:2) Octave	1 1
(2:3) P 5th	2 1 1 2
(3:4) P 4th	3 1 2 2 1 3
(3:5) M 6th	3 2 1 3 1 2 3
(4:5) M 3rd	4 1 3 2 2 3 1 4
(5:6) m 3rd	5 1 4 2 3 3 2 4 1 5
(5:8) m 6th	5 3 2 5 1 4 4 1 5 2 3 5
(5:9) m 7th	5 4 2 5 3 2 5 2 3 5 1 4 5
(9:10) M 2nd	9 1 8 2 7 3 6 4 5 5 4 6 3 7 2 8 1 9
(8:15) M 7th	8 7 1 8 6 2 8 5 3 8 4 4 8 3 5 8 2 6 8 1 7 8
(15:16) m 2nd	15 1 14 2 13 3 12 4 11 5 10 6 9 7 8 8 7 9 6 10 5 11 4 12 3 13 2 14 1 15
(70:99) Tritone	70 29 41 58 12 87 17 116 46 145 75 174 104 203 . . . etc.

TABLE II

INTERVALS GROUPED ACCORDING TO DENSITY

Low Density (Group 1)	Medium Density (Group 2)	High Density (Group 3)	Special Case: Extremely High Density
Unison Octave P 5th P 4th	M 6th M 3rd m 3rd m 6th	m 7th M 2nd M 7th m 2nd	Tritone

that of the tritone. A true tritone of three whole-steps is achieved by dividing the octave in two equal parts — i.e. 600 cents or the ratio 70:99 [31, 7].

(2) it is the only interval without an inversion. When the frequency of its lower tone is doubled, the interval response remains exactly the same — e.g. 70:99=1.414; 99:140=1.414. The density scale illustrates the extreme complexity of the tritone; its symmetry accounts for its ambiguity.

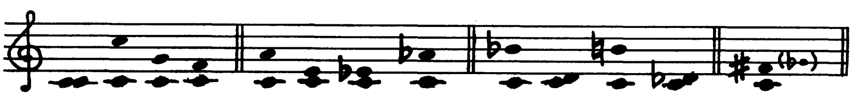
(3) it is the only high-density interval essentially free of beating. Seconds and sevenths, in certain registers and at certain decibel levels, beat violently; but, as noted later, beating has nothing to do with the density phenomenon.

For the sake of convenience, the intervals may now be divided into four general classifications. These groupings are made on the basis of similarities between density patterns of the various intervals.[6]

The intervallic groupings in Table II may be notated musically as in Ex. 5. Similar (but incomplete) arrangements of interval values occur sporadically throughout acoustical literature (Helmholtz, Watson, etc.); but the reader is reminded that previous classifications of intervallic sonorities have been made mostly on a basis of "roughness" or "fusion" and, in contrast to the present method, have not actually produced visual evidence to show the reason for disposition of the intervals in a certain order. To say that an interval is "rough" does not show objectively how or why it is rough.

Example 5.

Low Density (Group 1)	Medium Density (Group 2)	High Density (Group 3)	Special Case (Group 4)



The theory that a graduation of interval values is dependent upon combination tones [14, 57-81] is even more questionable. Outstanding among the many weaknesses of this approach is the fact that combination tones vary with loudness levels [8, 292-6], as well as Steven's observation [27, 184] that difference and summation tones are produced only in the ear [see also 1, article "Combination Tones"].

writer in the Acoustics Laboratory of the Massachusetts Institute of Technology.

6. See pp. 198-200 of this article concerning the relation of intervals to their inversion.

Beating — the interference phenomenon heard as minute intensifications of sound at regular periods — is an important factor in intervallic perception, being a characteristic feature of the high-density intervals in Group 3. It has also been noted, however, that beating is not an objective phenomenon but a subjective one[7]; "it is only because the two tones force into vibration two overlapping regions of the basilar membrane that an alternate waxing and waning of sound is heard" [27, 241]. Furthermore, the number of beats generated by an interval is not constant in different registers. There are only about 4 beats, for example, between c'' and d♭'', but between c'''' and d♭'''' there are about 16 [31, 12, 16]. Beating, whether of fundamental tones or harmonic partials, should not be confused with density.

Also, the distinction between the density concept and "small-number" theories of the past must be clearly understood. The latter held that tones whose frequencies were related as "small numbers" formed consonant intervals. This use of the word "consonant," as we have noted already, had no real significance in functional music, and to say that the ratio 1:2 produced a "smooth" interval did not show why or how such an interval might be rougher or smoother than another.

The concept of density not only provides visual description of relative complexity — regardless of register — but offers also a tangible scale of intervallic relationships which can be used to establish a mean rate of information exchange. The fact that all intervals besides the octave may be slightly mistuned and yet retain their essential identity does not detract from the potential usefulness of the density scale. Although the computation of intervallic complexity was necessarily worked out in terms of ideal interval ratios, slightly mistuned intervals will still retain the same relative degrees of complexity. The reader is reminded again of the ear's ability to discriminate the mean relationship between discrepancies in tuning and pitch ratios.

Caution should be exercised in applying the density concept to intervals exceeding the octave. The true nature of the octave phenomenon in music does not yet seem to be understood clearly. Révész has advanced the idea that the qualitative equivalence of tones an octave apart is due to their "phenomenological similarity" [24, 61] — i.e. there is "something" about tones separated by one or more octaves that makes them appear similar in quality, but not identical (contrary to popular belief). At any rate, the question has not been settled as to whether an eleventh, for example, is perceived as an intervallic unit (Gestalt) or as a perfect fourth by instantaneous octave adjustment. It is the writer's opinion that the latter states the case accurately since any interval, say a major seventh, can be made to sound like an octave duplication (on first impression) simply by sounding the two tones sufficiently far apart. An interesting experiment is related by Schillinger [26, 699] wherein trained musicians were unable to distinguish between short fragments of Grieg's Peer Gynt Suite played at the unison, and then at the seventh with a three-octave separation. In all probability

7. "Objective" and "subjective" are used advisedly here to differentiate between stimuli outside the skin as opposed to internal response. The density scale is a description of objective, physical phenomena in the time-domain.

the ear judges intervals exceeding the octave in terms of its familiarity with intervals within the octave, and musical situations evaluated in terms of the latter will have essentially the same perceptual, if somewhat "distilled," effect. Therefore, density patterns within the octave are assumed to be adequate for the majority of musical problems.

The evaluation of intervals according to their stability-instability potential may now be achieved by means of density ratings, which provide a basis for the determination of simplicity-complexity patterns evolved from the juxtaposition of intervallic areas. The classification of static sonorities according to their relative complexity (density) provides a general approach to the understanding of consonant-dissonant relationships as found in Western music from c. 850 to the present. The density scale does not assort the intervals according to their consonance or dissonance, but offers criteria for the analysis and synthesis of functional intervallic relations according to context. Let us remember that consonance and dissonance in this study are regarded as functional combinations of tones which respectively stimulate responses of stability or instability.

An individual's reaction to observable phenomena, acoustical or otherwise, may be examined more readily with the help of a scale of measurement known as the Mean Rate of Information Exchange (RIE), which provides a general method for describing the relation between under-stimulation and over-stimulation. In music, for example, communication between the composer and listener might never be established if the latter received either too little or too much information from a particular composition. A highly complex piece of music might leave even the well-trained listener in a state of confusion and aesthetic frustration, and an absurdly simple composition might elicit from the same person either no response or, at best, expressions of boredom. Yet somewhere between these two extremes there lies an area of "knowledgeable evaluation" or "appreciation" wherein the trained listener experiences a normal rate of information exchange, and where he is able to perceive the composer's general intentions. This area of "normal" response is not unlike the point of balance which Heraclitus felt existed between the action of opposites.

Acoustically, a mean "sense of proportion" will be found somewhere between the under-stimulation of a single pure tone and the over-stimulation of tonal cacophony (e.g. successive, simultaneous blows of both forearms on the piano keyboard) which may be meaningless to the point of being described as "noise." Graphically, the mean RIE can be illustrated as follows:

RATE OF INFORMATION EXCHANGE SCALE

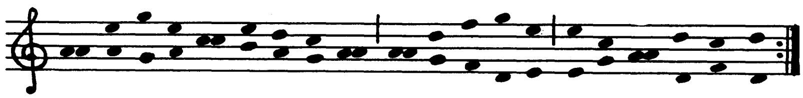
ZERO ←		→ INFINITY
Simplicity, under-stimulation	Hypothetical area of normal response	Extreme complexity, confusion, over-stimulation
↓	↓	↓
A single pure tone	Comprehensible rhythmic, melodic and tonal organization.	Tonal cacophony

It is in the above-indicated "normal" area that, as Cazden puts it [7, ix], "the content of the music must be communicated somehow in its tangible sounding performance"; also it is with the aid of this terminology that music from various periods may be described objectively, without resorting to conflicting definitions. One might speak, for example, of a compositional style as being disturbing due to its extremely complex RIE or, perhaps, as being pleasing due to its balanced and relatively normal RIE. An objective method of controlling or evaluating the potential RIE of a given intervallic set is available through the use of the density scale. A too-rapid rate of information exchange might very correctly be described as dissonant, since the reference would be to a disturbing functional situation. Again, however, no interval in isolation should be called consonant or dissonant but, rather, should be referred to as having "low density," "medium density" or "high density" and therefore as being potentially stable or unstable.

A contrapuntal situation involving low-density intervals from Group 1 is shown in Ex. 6 (p. 196). The RIE (rate of information exchange) in this example borders on under-stimulation due to the complete absence of medium- or high-density intervals which would tend to add elements of stress. Compare Ex. 6 with Ex. 7 which uses high-density intervals almost exclusively. The RIE in Ex. 7 borders on over-stimulation due to the almost complete absence of medium- and low-density intervals which would tend to add elements of repose. A mean balance between the above extremes can be obtained by using frequent medium-density intervals or by combining low, medium, and high as in Ex. 8. The RIE of Exx. 8a) and 8b) should be within the area of normal response due to the balanced use of low- and medium-density intervals, in combination with a smaller number of high-density intervals.

Scoring, dynamics, and various coloristic devices can be used to obscure the simplicity-complexity relations of intervallic areas, but the density scale furnishes a generally concrete approach to the analysis of consonant-dissonant situations. Note how the consonant (balanced) effect of Ex. 9 (p. 197) is abruptly disturbed by the sudden and unwarranted insertion of a high-density interval in m. 5, thus producing a dissonant (unbalanced) response at that point. Yet, the same chord-structure fails to evoke a dissonant response if it occurs in a different

Example 6. <u>Cunctipotens genitor</u> (11th-century free organum).



Example 7. Minor 2nds, Major 7ths (Bela Bartók).

Molto Adagio

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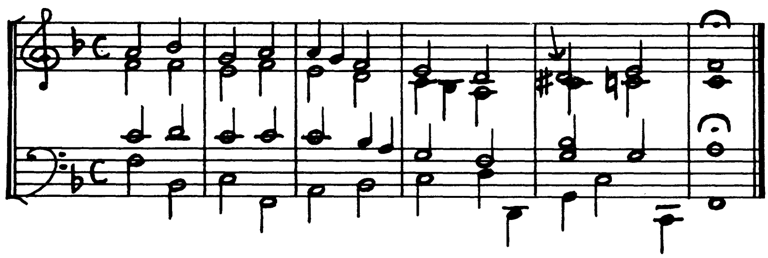
Example 8.

a)

b)

Example 9.

Slowly



Example 10.

Moderately

setting (Ex. 10).

No interval, therefore, can be termed consonant or dissonant without consideration of context; but this does not eliminate the classification of isolated intervals, since now we can evaluate them in terms of their relative density and actually visualize their probable tendency toward under-stimulation or over-stimulation.

The similar quality of inverted intervals is also explained by the density scale. The perfect fifth (2:3), when inverted, becomes a perfect fourth (3:4), but what is there about the density rating of these intervals that explains their similarity in quality?

An interval is said to be inverted when the frequency of its lower tone is doubled, or when the frequency of its upper tone is halved. Inversion is also the process of reversing the relationship between two tones so that the common product (C.P.) of their frequencies is doubled (or vice versa). The common product of the ratios forming a major third (4:5), for example, equals 20. The product of the ratios forming its inversion, the minor sixth (5:8), equals 40. Also, the various density patterns which result from the wave superposition might be expected to display multiple relationships when an interval is compared with its inversion, i.e. the density rating of an interval should be doubled (or halved) when the interval is inverted. This is exactly the case, since the density pattern of a perfect fifth (2112, totaling 6 fluctuations), doubles itself when inverted to a perfect fourth (312213, totaling 12 fluctuations). Furthermore, that position of an interval whose ratio yields the largest common product manifests a density pattern which is directly related to the density pattern of its inversion. This relationship is expressed by means of duplicate numbers and also integers resulting from the summation of terms in that inversion with the smallest C. P.

Assume, for example, that the two intervals in question were the perfect fifth and its inversion, the perfect fourth. By referring to the density scale in Table I (p. 191), it is seen that the periodic complexity pattern of the fifth is 2112; of the fourth, 312213. The frequency ratio of the latter is 3:4 (C. P. = 12); that of the former, 2:3 (C. P. = 6). The fourth, therefore, having the largest common product, contains integers in its density pattern (Ex. 11, p. 199) which result from a summation of terms (in brackets) in the density pattern of the fifth. The same holds true for all other intervals and their inversions. Ex. 12 illustrates the numerical relationship between the major third and minor sixth. Note that numbers in the periodic pattern of the minor sixth are either duplicates or the result of summed terms from the major third's density pattern.

The significance of this seemingly abstract analogy should not be overlooked by the reader. Remember that the various numbers in all the density patterns represent the time which elapses between moments in wave superposition when there is no reinforcement or cancellation of amplitude. When an interval is inverted these moments remain essentially the same, with the exception that some of the terms combine to form larger integers in the inverted interval. It is not surprising, therefore, that a similar quality exists between an interval and its inversion. The writer submits that this similarity in quality is largely

Example 11.

Perfect 5th (C. P. 6) 2112 / 2112 / 2112 / 2112

Perfect 4th (C. P. 12) 3 12 / 21 3 / 3 12 / 21 3

Example 12.

Major 3rd (C. P. 20) 41322314 / 41322314

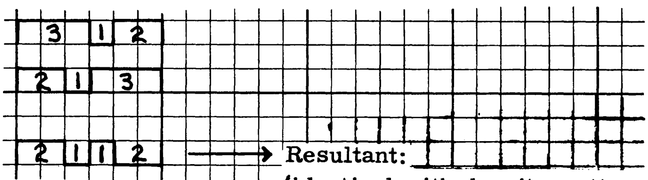
Minor 6th (C. P. 40) 5 32 514 / 41 523 5

Diagram 11.

Perfect 4th (3:4) 3 1 2 ¦ 2 1 3

Axis
of
Symmetry*

Displaced in simultaneity:

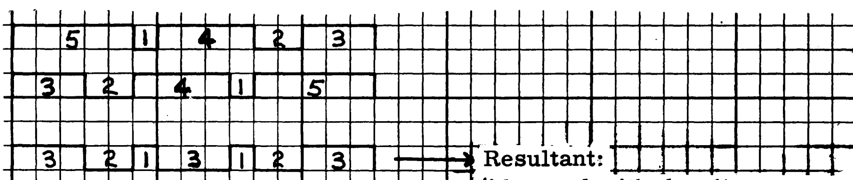


(identical with density-pattern
of the perfect fifth)

Minor 3d (5:6) 5 1 4 2 3 ¦ 3 2 4 1 5

Axis
of
Symmetry*

Displaced in simultaneity:



(identical with density-pattern
of the major 6th)

*That point after which the number pattern repeats itself in reverse order.

due to coincident events in the time-domain, and that these events may be described in terms of numerical relationships between density patterns of the intervals.

The inextricable bond of periodic complexity between an interval and its inversion is further evidenced by displacing the density pattern of any interval in simultaneity from its axis of symmetry (start with that position whose ratio yields the largest common product). The resulting periodicity corresponds identically to the inversion of that interval (Diagram 11).

The potential tendency towards stability of all types of chord-structures may be evaluated by means of the density scale. The reader is reminded again, however, that the roughness caused by beating has nothing to do with the density theory per se. The diminished-7th chord, for example, contains no intervals that "beat," but still has a pronounced forward tendency to move to another harmony due to the presence of two high-density tritones. The relative stability of all intervallic sonorities is based on the following principle: <u>structures with the highest density rating will have the strongest tendency toward instability.</u>

In Table II (p. 191) the various intervals were classified as low density (unison, octave, fourth, fifth), medium density (thirds, sixths), high density (seconds, sevenths), and the tritone as a special case. These four groupings are used as a convenient basis for the computation of relative stability:

(1) Group 1 intervals are given a rating of 1;
(2) Group 2 intervals are given a rating of 2;
(3) Group 3 intervals are given a rating of 3;
(4) The special-case tritone is given a rating of 4.

The density ratings of various structures may be obtained easily by using the above classification. Among the 3-part (3p) structures, for example, the four common types of triads[8] would be rated as follows:

S5 maj: contains 1 interval from Group 1 and 2 from Group 2.
Density rating = 5

S5 min: contains 1 interval from Group 1 and 2 from Group 2.
Density rating = 5

S5 aug: contains 3 intervals from Group 2.
Density rating = 6

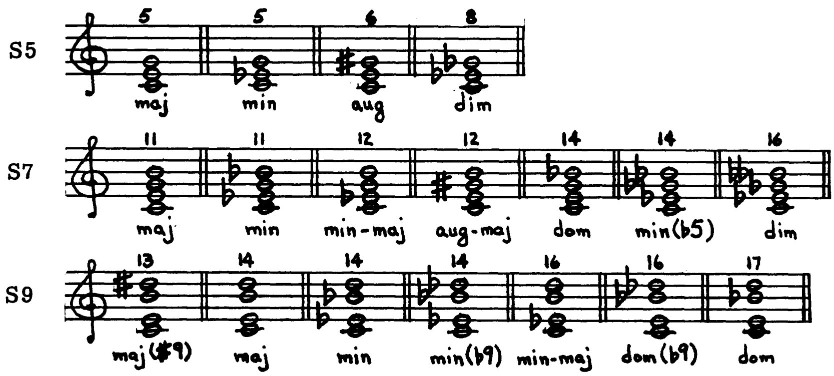
S5 dim: contains 2 intervals from Group 2 and one from Group 4.
Density rating = 8

8. As suggested by Schillinger [26, Book V], S5 (S = structure) denotes a triad built in thirds; S7, a 7th chord built in thirds; S9, a 9th chord built in thirds.

TABLE III

DENSITY ANALYSIS OF STANDARD CHORDS

Chord Structure		Number of Intervals in Each Group				Total Density
		1	2	3	4	
	maj	1	2	0	0	5
S5	min	1	2	0	0	5
	aug	0	3	0	0	6
	dim	0	2	0	1	8
	maj	2	3	1	0	11
	min	2	3	1	0	11
	min-maj	1	4	1	0	12
S7	aug-maj	1	4	1	0	12
	dom	1	3	1	1	14
	min (♭5)	1	3	1	1	14
	dim	0	4	0	2	16
	maj (♯9)	1	3	2	0	13
	maj	1	2	3	0	14
	min	1	2	3	0	14
S9	min (♭9)	1	2	3	0	14
	min-maj	0	3	3	0	15
	dom (♭9)	0	3	2	1	16
	dom	0	2	3	1	17



Observe that these ratings correspond to the traditional treatment of the above triads — i. e. the augmented triad is considered less stable than the major or minor, and the diminished triad is the least stable of all due to its high density rating. Ratings for the 7th chords (S7) and 9th chords (S9) are derived in the same way. Table III (p. 201) shows comparative density ratings for triads, 7ths and 9ths. To avoid confusion in terminology, these structures are shown below Table III in musical notation. The number above each chord is its density rating.

The same principle applies to progressions of less common structures. The isolated chords in Ex. 13 (p. 203) can be arranged so as to express increasing instability (approach to climax) or increasing stability (approach to cadence, or point of rest) simply by distributing them in accordance with their increasing or decreasing density. Increase in forward tendency (instability) indicated by ; decrease in forward tendency (stability), ; no change (neutral), .

Two chords with the same apparent density rating — e.g. the second and third chords in Ex. 13b) — may still be evaluated comparatively by examining each structure more closely. Note that the second chord in Ex. 13b) contains two intervals from Group 1, three intervals from Group 2, and only one from Group 3, whereas the third chord contains two intervals from Group 3. Since the latter chord has more Group 3 intervals than the former, it is considered to be less stable, even though the overall density rating for both structures is the same. The general rule for comparing chords with the same rating is as follows: When two or more structures have the same density rating, that structure containing the most intervals from the group with the highest density rating will have the strongest tendency towards instability.

In Ex. 14 (p. 203) there are several chords with the same rating. It is still possible, however, to evaluate the relative stability of these structures by determining which chords have the most intervals in groups with higher ratings. Note that chord E in Ex. 14, not containing the tritone, has greater stability than the other chords with a rating of 14; and although chord D contains a tritone, it does not have as many Group 3 intervals as B and C. There is no change in stability between chords G and H since both these structures have the same kinds of intervals from the same Groups — i. e. each has a perfect fourth, major sixth, two major thirds, a minor sixth, and a minor second.

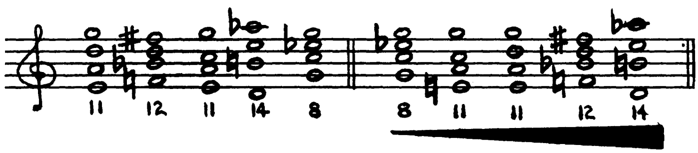
In general, chord progressions are normally controlled by:

(a) stability-instability of vertical structures;
(b) linear motion of individual parts;
(c) any combination of (a) and (b).

Stability-instability tendencies of the above progressions were controlled by redistribution according to density ratings, but activity in progressions such as the following results from linear part movement towards cadence points, not from structure. Note the predominately "neutral" effect of the harmony in Ex. 15 all structures of which have the same density rating — i. e. 5 (each chord contains one Group 1 interval and two Group 2 intervals).

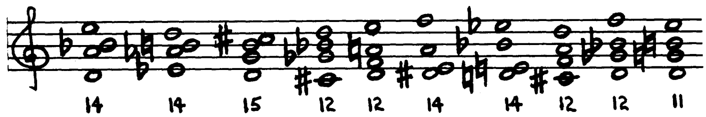
Example 13.

a) Original progression. b) Redistribution to express increasing instability.

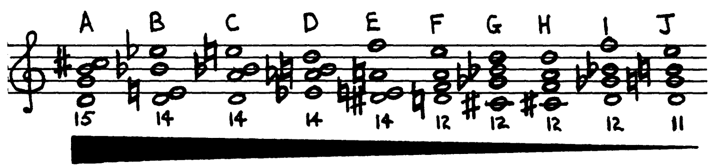


Example 14.

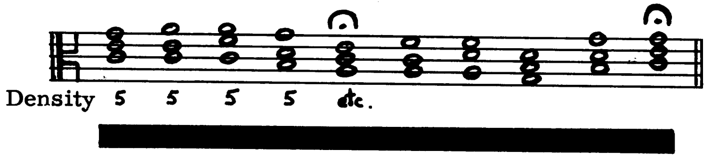
a) Original progression.



b) Redistribution to express increasing stability (cadence).



Example 15.



Pressure changes resulting from molecular compression variations are brought about by the tremulous motion of material objects, which causes a displacement of air particles. This action results in an alternation of particle condensation and rarefaction constituting the phenomenon known as vibration, and the hearing response to vibratory motion is termed sound. Regular air vibrations with a speed of around 16 to 40 times per second and faster may be perceived as pitch; the sensation of interval is produced by combining two or more pitches. The amplitude-periodicity relationships (in the time-domain) between two tones may be established by examining the points in time where no reinforcement or cancellation exists between wave trains, and between which points all pressure fluctuations take place that produce patterns of change in particle activity. These patterns, reflecting the intensity of molecular activity in a perceivable intervallic area, provide the means for measuring the relative density of such an area, thus paving the way for a scale of absolute intervallic sonority.

The density scale, which does not vary appreciably with register or intensity (as do beats and combination tones), offers visual evidence of the probable tendency of the intervals towards stability or instability. The medium-density thirds and sixths of Group 2, serving as a convenient mean between extremes, have provided a relatively stable foundation for most of the music in Western civilization (especially since c. 1450). The unprecedented popularity of these intervals is evidenced by many rules of traditional theory, one of the more interesting of which is the principle that thirds and sixths are the only intervals permitted to move in parallel motion in strict counterpoint [12, 20]. Parallel motion between the low-density octave and fifth, or the high-density seconds, sevenths and tritone, is strictly forbidden [12]; but the "middle ground," less sharply defined thirds and sixths have received the blessings of pedagogues for many years. They have been, in fact, the "normal expression of consonant moments in the musical system of the tonal era" [7, 297].

The answer to Aristotle's query, "Why is it that the difference of an octave may be undetected and appear to be unison?" [2, 385] is relatively simple when viewed in terms of density ratings. The octave is the only interval besides the unison whose periodic complexity pattern contains no integers other than the number "1" (i.e. complete uniformity) and, by comparing the density of the two intervals, it is seen that the pattern for the octave is nothing more than a duplication of that of the unison.

The high density intervals of Groups 3 and 4, on the other extreme, manifest a complexity that warrants careful handling. Even today, an intervallic framework which fails to use these intervals judiciously is in danger of stimulating a response which lies beyond the normal area of information exchange — i.e. to many listeners, the musical situation tends to be too complex for aural comprehension — witness, for example, many works of the "atonal" school, such as Schonberg's Suite, Op. 25, Berg's Lyric Suite, Krenek's Karl V, etc.

In addition to explaining the similar quality of inversions and helping to establish criteria for a normal RIE, the density scale is especially valuable for judging the relative stability of chord-structures. Although any chord can be made to sound consonant (stable) or dissonant (unstable) by adjusting the musical context, it is still extremely important to realize that some structures have a more pronounced tendency towards instability than others.

The density scale serves as a source of criteria for establishing group-ratings for the various intervals. These ratings provide an objective method for the evaluation and control of stability-instability patterns, and eliminate the necessity for using conflicting pseudo-definitions. The expressions "consonant" and "dissonant" may now be reserved for strictly functional situations where, in the writer's opinion, they properly apply; and isolated intervals can be described as low-density intervals, medium-density intervals, and high-density intervals.

The latter classifications offer the theorist and music educator objective, relatively concise language for the analysis and synthesis of widely divergent musical styles. It should be necessary no longer to teach beginning students that one set of intervals must be categorized as "consonances" and another as "dissonances," only to ignore these classifications in musical practice. In view of the impracticality of the continued use of these words to describe both the functional (musical) and non-functional (laboratory), it seems advisable to employ terminology which avoids the connotative contradictions of the past. The need for new language is acute. Perhaps the density scale can meet this need.

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