I

INTRODUCTION

PRELIMINARY

Instrumentation is both an art and a craft. As an art it is a matter of choosing, ordering, and blending timbres—one facet of the greater art of composition, which also involves choosing, ordering, and blending pitches, dynamics, and durations. As with all arts, it cannot be reduced to rules or formulas but must be learned through intuition, imitation, and painstaking trial and error.

The *craft* of instrumentation, with which this book is concerned, is a purely factual discipline, consisting of the knowledge and understanding of the capabilities, limitations, and idiosyncracies of the numerous devices that are used to transform music from dots on a page into sound. The musical devices involved include not only everything that can be called a musical instrument but also the human voice and a wide variety of electronic equipment; these are included in the term "instrument" wherever it occurs in this book.

Musical instruments have traditionally been classified into a number of broad categories, based on the manner in which the sound is produced: **winds** (subdivided into **woodwinds** and **brasses**), **voices**, **percussion**, **keyboards**,* **strings**, and **electronic equipment**. In scores of all sorts it is the usual practice to order the instrumental lines according to these categories; the order of the categories is standardized, and the position of instruments within each category is also standardized.

* Many writers do not recognize the keyboards as a distinct group, but instead divide them among the various other categories.

CLASSIFICATION OF INSTRUMENTS

Woodwinds	*Brasses*	*Voices*	*Strings*
flutes	horns	children	harp
oboes	trumpets	women	guitars
clarinets	trombones	men	violins
saxophones	tubas	*Percussion*	*Electronics*
bassoons		*Keyboards*	

The position of voices, keyboards, and electronics within this scheme is not fully standardized, and alternative page-positioning of these instruments is discussed at the beginning of the appropriate chapters. The instruments in Part One of this book are discussed in score order.

Most instruments are made in a variety of different sizes, comprising a **family** of instruments all basically the same in timbre and technique but differing in pitch range. When several sizes of the same instrument are used together in a score, the highest (smallest) variety appears first, followed by the others in descending order. Thus, for instance, the piccolo will be found at the top of any system in which it appears, since the flutes come first in the basic order and the piccolo is the highest of the flutes. It should be understood, however, that each line of music in score corresponds to a single *player*, not necessarily to a single instrument: if a player is required to **double**, that is, to play two or more different instruments, the position of the player's line in the score does not change relative to the others even though this may put an instrument out of sequence. This is particularly important in the percussion, since percussionists are expected to play all the instruments in that category, and a part may require a dozen or more different instruments. This aspect of percussion writing is discussed at length in Chapter V.

The instruments covered in Part Two of this book have discontinuous histories—they were all extinct for greater or lesser periods of time before being revived in the twentieth century for the performance of early music. The vast majority of them were extinct throughout the period when the traditional score-order discussed above was being developed, and hence there is no standard place for them in that order. Suggestions as to appropriate placements for them are advanced in Chapter XI. The "early" instruments are of course technologically simpler than the modern instruments discussed in Part One, and are less flexible, more idiosyncratic. Because of this, and because they are rather infrequently required in new compositions, they have been relegated to a separate section and should probably be studied only after the material in Part One has been absorbed.

In both parts of the book, the discussion of each family of instruments is headed by two or more diagrams. The first of these is a line drawing of all the members of the family drawn to the same scale, with a drawing of a meter-stick for comparison. The second diagram gives the "vital statistics" of each instrument in the family: its full name, the most commonly used abbreviations for that name, its written range, its transposition* (if any), and its availability. The range of most instruments varies depending on the abilities of the player and small differences in construction between individual instruments; in the vital-statistics charts the limits of the normal range are given with open ("white") notes, and any **extension range** is

* *Transposition* is explained in Chapter II.

shown with filled ("black") notes. The normal range given in each case is that expected as a matter of course from all professionals and first-rate amateurs; student players, however, may not be able to cover even this normal range completely (see Appendix II). When extension tones are available only on specially constructed instruments, the approximate percentage of such instruments presently in the hands of professionals and competent amateurs is usually indicated. Extension tones other than these can be produced on ordinary instruments but require the abilities of a virtuoso player.

The "extra" open and filled notes in the ranges of most instruments are provided as guideposts for the **dynamic range**, given just beneath; the loudest and softest dynamic levels an instrument can attain in the various parts of its pitch range are given there. It must be understood that, despite the appearance of these charts, changes in the dynamic range from note to note are usually gradual, not abrupt.

Traditionally, the notation of dynamics has been a compromise between two distinct concepts: the amount of effort exerted by the player to play loudly or softly, and the actual loudness of the sound. The exact balance between these concepts varies from composer to composer. If one strictly follows the first concept, a single invariant dynamic range will apply to all instruments at all points in their ranges, and different instruments may have to be assigned different dynamic levels to produce the same loudness. An example of this can be seen at rehearsal number sixteen in the *Sinfonia de Antigona* of Chavez, where in a duet for alto flute and heckelphone the two parts are marked, respectively, *ff* and *ppp*, the obvious intent being that both should produce a moderately soft sound. In this book, dynamic indications refer to the loudness of the sound, not to the effort put out by the player. Nine evenly spaced degrees of loudness are distinguished, from *ppp* (barely audible) to *ffff* (threshold of pain).*

The **availability** of each instrument is indicated by one of five terms (**ubiquitous**, **common**, **usually available**, **rare**, **very rare**). All the information in this book is based on U.S. and Canadian practice, and although in most respects European practice (or Australian or whatever) is not significantly different from that described here, the availability of many instruments abroad is not the same as in North America. It is, unfortunately, impossible to generalize about this.

Following the discussion of each family of instruments is a list of musical examples for each instrument in the family. These are pieces that prominently feature the instrument, displaying a wide range of effective and idiomatic writing for it. With a few exceptions, all these pieces are available both on record and in published score. At the end of each chapter is an additional list of pieces featuring large mixed groups of the instruments covered in that chapter.† Finally, at the end of Chapter IX is a list of works displaying the full resources of the orchestra. All these lists are divided approximately equally between works written before and after 1950, and *at least* one piece of each period should be studied in detail for each instrument, so that a balanced perception of their sound and general "feel" will be acquired. In studying the older scores, one should remember that the *instrumentarium* even of the early twentieth century was somewhat different from that of today. Instruments will be encountered that are now extinct (usually with good reason), and techniques now taken for granted may appear cautiously employed and elaborately footnoted. It is because of this constant evolutionary change in instrumentation that very few pre-twentieth-century pieces are

* Calculated for a moderate-sized hall of average acoustics.

† All percussion examples are listed at the end of Chapter V.

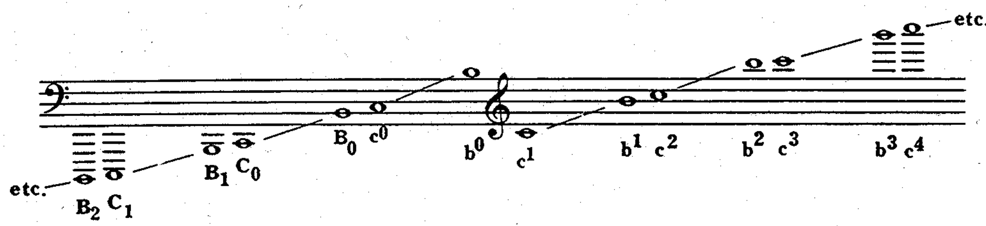

FIGURE 1. *Pitch names.*

𝄲 = *¼ tone sharp*	| = *¼ tone flat*
𝄰 = *¾ tone sharp*	|♭ = *¾ tone flat*

FIGURE 2. *Quarter-tones.*

cited here: the vast majority of instruments now in use differ quite radically in construction and technique from those used in the nineteenth century.

Students lacking access to a large music library should at least be able to borrow—or, better yet, acquire—the following works, which display most of the instruments in the book.

Stravinsky: *Le Sacre du printemps*
Agon
Schoenberg: *Theme and Variations*, Op. 43a
Varèse: *Ecuatorial*
Déserts
Messiaen: *Chronochromie*
Cage and Harrison: *Double Music*
Xenakis: *Oresteia Suite**
Crumb: *Ancient Voices of Children*

For Part Two, see any demonstration album of medieval and Renaissance instruments. Also, Mauricio Kagel's *Musik für Renaissanceinstrumente* is a veritable compendium of contemporary techniques for these instruments.

In the body of this text, capital letters without subscript numerals are used to refer to general pitch-classes. Individual pitches are identified by a now universal system of capital and lower-case letters and sub- and superscript numerals; this notation, summarized in Figure 1, should be memorized. Although the use of quarter-tones is by now quite common, their notation is not yet completely standardized. In this book the system given in Figure 2 is used. In addition, this book uses upward- and downward-pointing arrows to indicate "very slightly sharp" or "very slightly flat."

THE PHYSICS OF INSTRUMENTAL SOUNDS

Sound is created by any object vibrating in a fluid medium such as air. As the object moves through the medium, it strikes the molecules in its path, propelling them in its own direction at a speed that varies with the density of the medium. Since air is approximately the same density everywhere, this speed ("the speed of sound") is essentially constant. The air mole-

* At this writing (1981) the score to the *Oresteia Suite* is available only on rental. Until a study score of this important work becomes available, *Akrata* may be substituted.

cules so propelled "run into" the stationary air adjacent to them, creating a zone of high pressure and transferring most of their motion to the adjacent molecules, which in turn transfer their motion to still other molecules further down the line. The net result is a burst of high pressure that is propagated through the air at the speed of sound until its energy has been dissipated—much like a wavelet spreading outward from the spot at which a pebble is thrown into a pool of water. Note that individual molecules move only a short distance: it is the *wave* that does the traveling. With each oscillation of the vibrating object a new burst of pressure is sent out in the same way; and since the bursts all travel at the same speed, when they reach the ear they have the same frequency with which they left the vibrating object.

In the ear the bursts of pressure are transferred through the eardrum and the three auditory ossicles to the fluid in the cochlea. Within the cochlea different frequencies resonate in different places; the vibrations are registered by the auditory nerve and transmitted to the brain, which interprets the *location* of each stimulus within the cochlea as a pitch.

The human ear can register frequencies between approximately 16 and 16,000 Hertz (= complete back-and-forth vibrations per second),* that is, from about C_2 to c^7; however, the ability to discriminate differences in pitch is largely absent above about 8,000 Hz (c^6). Frequencies below 16 Hz, though they cannot be heard, can be felt by the whole body.

The relationship between frequency and pitch is exponential: two notes an octave apart have frequencies in the ratio of 2:1. Thus, since a^1 has a frequency of 440 Hz, a^2 lies at 880 Hz, a^0 lies at 220 Hz, and so on.

The vibration of a real object is not as simple and straightforward as one might think; there are wiggles and bends in its shape, slight hesitations in its motion. These complexities are reflected in the sound waves it produces in the air, and are heard by the ear as its **timbre**. In reality, any waveform, no matter how complex, can be analyzed as a combination of a number of pure tones called **partials**. Of these, the lowest (which is usually also the loudest and thus heard as "the" pitch of the note) is called the **fundamental**; the others (usually much softer) are called **overtones**. The exact relationship among the frequencies of the various partials depends on the nature of the vibrating object.

As an example, let us consider a plucked string. Theoretically, there are an infinite number of ways that a string can vibrate, but all of them involve division of the string into equal segments (Fig. 3). Each of these **modes of vibration** produces a different pitch, and since the actual vibration of a string contains some component of every mode, all the pitches are represented: these are the partials of string tone. The simplest mode of vibration, in which the whole string vibrates back and forth as a unit, produces the fundamental. The second vibratory mode, which divides the string into two equal parts, produces a frequency twice that of the fundamental; the third mode, dividing the string into three parts, produces a frequency three times that of the fundamental, and so forth, so the frequencies of all the partials are simple integer multiples of the fundamental frequency: 1/1, 2/1, 3/1, 4/1, etc.

Since the relationship between frequency and pitch is exponential, this linear series of frequencies produces a logarithmic series of pitches (shown in Fig. 4). This **harmonic series** is characteristic of the timbres not only of stringed instruments (both bowed and plucked) but also of all wind instruments (as explained in detail in Chapter II), the human voice (Chapter IV), and electronically produced triangle, square, and sawtooth waves

* Below the age of forty or so, most people can hear as high as 20,000 or 30,000 Hz. Young children can hear frequencies as low as 10 Hz.

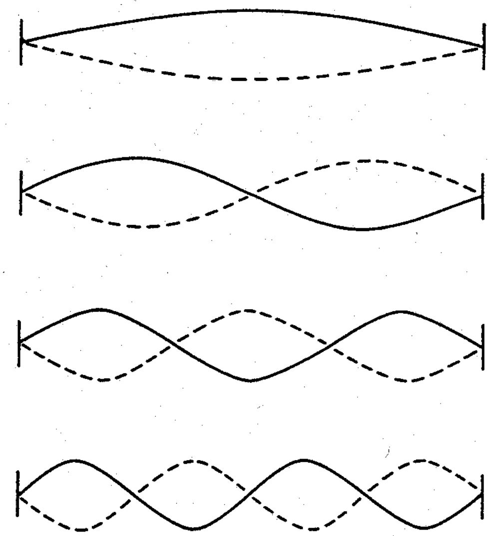

FIGURE 3. *Modes of vibration of a plucked string.*

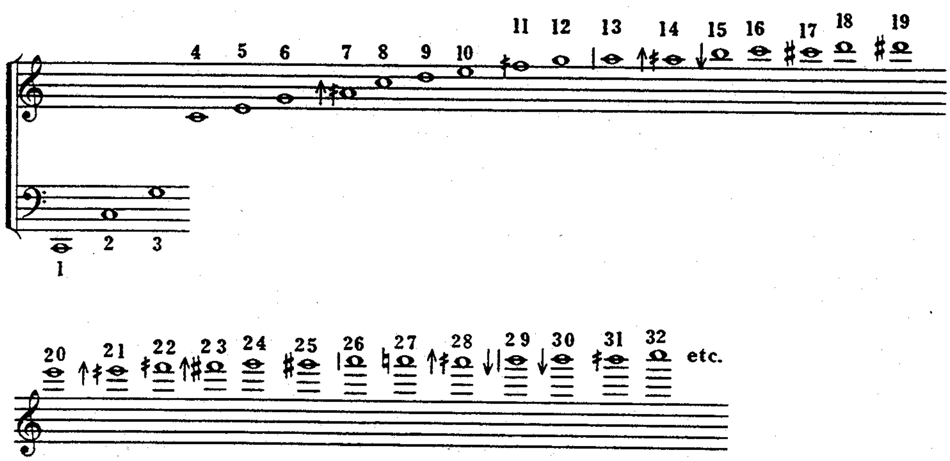

FIGURE 4. *The harmonic series of the note C_0.*

(Chapter X). The vibratory modes of drumheads and solid objects (Chapter V) are much more complex, and their frequencies, which can only be calculated by the use of some rather fearsome mathematics, are heard simply as irrational collections of sounds. These **inharmonic partials** give the sound of drums and bells a characteristic clangor that is also typical of such phenomena as multiphonics (Chapter II) and ring-modulation (Chapter X).

The harmonic spectrum of a sound is not the only determinant of its timbre. Equally important is the **envelope**—the contour of the sound as it develops over time, its pattern of attack and decay. The most important timbre-forming part of the envelope is the attack pattern; the recorded sounds of instruments as diverse as the piano, cello, and baritone horn become virtually indistinguishable if the attacks are removed. A typical attack pattern involves several features. First of all, the sound must start from zero and build up to its steady-state volume, and this may happen with great suddenness, gradually, or at some intermediate

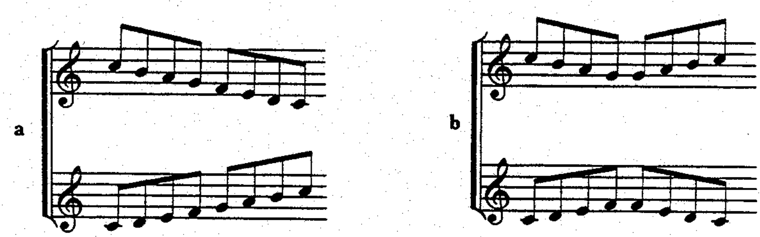

FIGURE 5. Trompe-l'oreille *effect from voice-crossing in identical timbres: (a) as written; (b) as heard.*

speed. Frequently the attack volume builds to a point *above* the steady-state volume and then comes back down. During the attack the harmonic spectrum changes, both in the relative volume of the various partials (the fundamental often enters rather late) and in their pitches, which often start out inharmonically. Finally, the **attack noise**—the sound of the woodwind player's tongue pulling back from the reed, of the brass player's lips parting, of a finger releasing a string—is an independent sound unrelated to the pitch produced. Attack noise can be heard very clearly, for example, when the highest notes of the piano are played *fortissimo*; indeed, in this case the attack noise is the loudest component of the sound. The attack noise has its own envelope, independent of that of the tone itself, and this has usually died away completely by the time the steady tone is set up. As far as decay is concerned, the most important point for the composer is the distinction between **sustaining instruments**, such as the violin or clarinet, in which the tone can be maintained at a constant or even increasing volume throughout its duration, and **nonsustaining instruments**, such as the piano, guitar, or vibraphone, in which the sound dies away automatically following the attack.

COMBINING INSTRUMENTS

Three factors must be considered when writing for instruments in groups: these are **balance**, **timbre matching**, and **timbre mixing**. The factor of balance is best learned through familiarity with the dynamic ranges of the instruments as given in the "vital statistics" charts. Its importance may be gauged from the fact that a differential of as little as one dynamic level is sufficient to make a single instrument stand out clearly from a mass of as many as fifty. An *ffff* roll on the tam-tam will completely drown out a hundred-piece orchestra, most of whose members can play no louder than *fortissimo*.

Timbre matching is the trickiest single aspect of instrumentation and is the area in which errors are most frequently made by the student. For purposes of timbre matching, pairs of instruments may be considered to have **identical**, **similar**, or **unlike** timbres. Identical timbres are possessed only by identical instruments; even closely related instruments from the same family have similar rather than identical tone qualities. Identical timbres are ideal for homophonic writing in which a single full sonority is wanted and in which the vertical aspect of the music is more important than the horizontal. Counterpoint in identical timbres does not readily admit of voice-crossing, for the ear will misinterpret the voice-leading (Fig. 5). This *trompe-l'oreille* effect can be avoided by assigning different dynamic levels or articulations to the two parts or by placing the players far apart.

No clear line can be drawn between similar and unlike timbres, but the distinction is an important one since the less similar two timbres are, the less well they will blend. Extremely dissimilar timbres produce an effect of superposition: the two parts appear to occupy entirely different harmonic worlds, without harmony or counterpoint between them.*

The degree of blend is strongly affected by the horizontal and vertical density of the parts to be instrumented and by the overall height or depth of pitch. Parts that lie close together blend more easily than those that are widely separated in pitch, rhythmically similar parts blend more easily than those that are rhythmically diverse, and a little experimentation at the piano will show that low notes blend with each other much more easily than high ones. In addition, there are two general principles which should be remembered:

1. Sustaining and non-sustaining instruments blend with each other poorly at best, though each blends well with others of its own type.
2. Woodwinds, brasses, voices, and string instruments with fingerboards sound most distinctive (i.e., stand out most clearly, blend least well) at the bottom of their ranges; all other instruments sound most distinctive in the middle of their ranges.

The way all this works in practice can only be learned through frequent and intense analytical listening, score in hand—particularly to chamber music, in which the interactions between pairs of instrumental lines can be observed clearly. In the musical examples listed in the following chapters, one should study not only the specific instrument cited but also the ways in which that instrument reacts with the other instruments in the ensemble. In a wind quintet (flute, oboe, clarinet, horn, bassoon), for instance, the instruments blend well only at high pitches and the composer must constantly fight the tendency of this diverse ensemble to fly apart into its component parts in an unmediated five-voice wrangle. Contrast this with the string quartet (two violins, viola, cello), in which, because of the homogeneity of the ensemble, the blend is virtually perfect at all pitches. Or take the example of a sustaining instrument accompanied by piano—a song, for instance, or a sonata. Here almost the whole harmonic world of the piece is created by the piano, which in most musical circumstances quite literally "accompanies" the solo line rather than interacting with it, except by opposition and dialogue, both of which stress the relative immiscibility of the two sounds.

Timbre mixing requires less caution and more imagination than timbre matching. Just as a painter mixes the colors on the palette to produce new colors, so in instrumentation the tone colors of the various instruments can be mixed to form timbres unobtainable from any single instrument. Most timbre mixing is simple unison doubling, and the simplest form of unison doubling is **massing**, in which two or more identical instruments play the same material. The most familiar examples of massing are the five standard sections of massed bowed strings in the orchestra and the three sections of massed clarinets in the concert band. The sound of massed instruments has somewhat less character than the equivalent solo timbre; in particular, the attack patterns of the individual instruments are largely lost in the mass sound. In partial recompense, the sound of massed instruments has a unique turbulent quality, due to slight differences in pitch. The greater the number of players involved in producing a massed timbre, the more pronounced these characteristics become. The differences between

* This is just as true of music composed of noises or "sound events" as it is of more traditionally conceived material. References in this book to "harmony," "counterpoint," and so on should be interpreted in this light.

solo and massed timbre can be heard clearly in violin concertos, in which the solo violinist is regularly contrasted with the two orchestral sections of massed violins.

The violin concerto is also a good illustration of another feature of massed sound, viz., that massing produces very little augmentation of the volume of sound. As mentioned above, it takes a massed body of roughly fifty players to produce a sound one dynamic level higher than the sound of the individual players within the mass. The reason for this lies in the acoustical phenomenon of **interference**: the high-pressure crests of the sound waves from one instrument may correspond with the low-pressure troughs of sound waves from another, in which case the two cancel each other, producing a reduced volume or, if the correspondence is perfect, complete silence. In reality, the suppression of sound by interference within a mass of instruments almost exactly cancels the increase in volume one would expect from having multiple instruments.*

Mixed unison doubling is a very simple matter. The sound produced by a unison of nonidentical instruments is exactly intermediate between the instruments involved, in a very obvious way. One soon becomes able to imagine the sound of such combinations even when one has not heard them before. The only detail worth mentioning on this subject is that when a sustaining instrument is mixed with a non-sustaining instrument, the tone of the latter will have its effect for the most part only at the beginning of the combined sound and will be heard as a special attack pattern appended to the beginning of the sustaining instrument's tone. The most striking mixed unisons are those that involve unlike timbres, for when the two parent timbres are very distinct from each other their combined sound will also be distinctive.

A more complex and subtle form of timbre mixing involves the building up of a new timbre "from scratch" by assigning instruments to play not only the note itself but also upper partials of the note being doubled. A simple example of such an **artificial timbre** is the cliché octave doubling of the nineteenth century. Doubling of non-octave partials has been little explored (it occurs most frequently in the works of French composers from Debussy on), and it is admittedly tricky to fool the ear with such sounds. For such a combination to be successful the following conditions should generally be observed: first, that lower partials should be louder than higher ones, with the fundamental and/or second partial being loudest of all; second, that the fundamental should have a strong, bright timbre of its own, while the upper partials should be comparatively smooth and pure. A good example of a complex artificial timbre of this type can be found after rehearsal number 5 in Ravel's *Bolero*, where five partials of the melody are doubled. It is possible to construct artificial timbres with inharmonic partials, but these are more difficult to bring off than are those built on harmonic ratios. In order for the ear to be convinced that the sounds produced really are a single sound, either the partials must be many and dense (as in the sound-blocks of Ligeti and other Eastern European composers), or the fundamental must be at least two dynamic levels louder than any of the other partials. An example of an inharmonic artificial timbre is found at number 40 (and again at number 87) in Messiaen's *Couleurs de la cité céleste*.

* Interference takes its toll even when the instruments are playing different pitches. The totally *divisi* string sections of Ligeti and Penderecki are only marginally louder than ordinary massed unisons.