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MODERN PIANO TUNING
AND
ALLIED ARTS

INCLUDING

Principles and Practice of Piano Tuning, Regulation of Piano Action, Repair of the Piano, Elementary Principles of Player-Piano Pneumatics, General Construction of Player Mechanism, and Repair of Player Mechanism

BY

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Author of "Theory and Practice of Pianoforte Building," "The Player-Piano Up-to-date," and other works

WITH DRAWINGS, DIAGRAMS, TABLES, NOTES AND AN INDEX

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TO

THE CONFERENCE OF

AMERICAN PIANO TECHNICIANS

MEETING IN CHICAGO, U. S. A.

Whose valuable and exhaustive discussions
mark an epoch in the development of
American musical technology,

This Book

is, by one who has the honor of
membership in that Conference,

RESPECTFULLY AND AFFECTIONATELY
DEDICATED

PREFATORY NOTE

In writing this book, I have tried to do two things which are always thought to be admirable but seldom thought to be conjunctible. I have tried to set forth the theory of Equal Temperament in a manner at once correct and simple. Simultaneously I have tried to construct and expound a method for the practical application of that theory in practical tuning, equally correct, equally simple and yet thoroughly practical.

The construction of the piano has not in this volume been treated with minuteness of detail, for this task I have already been able to perform in a former treatise; but in respect of the sound-board, the strings, the hammers and the action, the subject-matter has been set forth quite elaborately, and some novel hypotheses have been advanced, based on mature study, research and experience. Here also, however, the theoretical has been justified by the practical, and in no sense have I yielded to the temptation to square facts to theories.

In the practical matters of piano and player repairing, I have presented in these pages the results of nineteen years' practical and theoretical work, undertaken under a variety of conditions and circumstances. In writing this part of the volume I have had the inestimable advantage of the suggestions and experiences of many of the best American tuners, as these have been gathered from past numbers of the Music Trade Review, the Technical Department of which paper I have had the honor to edit and conduct, without intermission, for fourteen years.

The preliminary treatment of the Acoustical basis of piano tuning may seem elaborate; but I have tried to handle the subject-matter not only accurately but also simply; and as briefly as its nature permits. The need for really accurate information here justifies whatever elaboration of treatment has been given.

I desire here to express my thanks to Mr. J. C. Miller for permission to utilize some of his valuable calculations, to Mr. Arthur Lund, E. E., for drawings of acoustical curves, and to my brother, Mr. H. Sidney White, M. E., for diagrams of mechanical details.

Most books intended for the instruction and guidance of piano tuners have been either so theoretical that their interest is academic purely; or so superficial that accuracy in them is throughout sacrificed. I have tried to avoid both errors, and to provide both a scientifically correct text-book for teaching and a pocket guide for the daily study and use of the working tuner. The program has been ambitious; and I am conscious, now that the task is finished, how far short of perfection it falls. But I think it fills a want; and I ask of all practitioners and students of the noble art of tuning their indulgence towards its faults and their approval of any virtues it may appear to them to possess.

The writing of the volume began in the winter of 1914 and was completed during the spring of 1915. Various causes have operated, however, to retard its publication; notably the sudden passing of the honored man whose encouragement and kindness made possible the publication of the other books which have appeared over my name. It is however fortunate that the successor of Colonel Bill, the corporation which now bears his name and is carrying on so successfully his fine work, has been equally desirons with me, of pushing the book to publication. A thorough rereading of the manuscript, however, during the interim, has suggested many slight changes and a number of explanatory notes, which have been incorporated with, or appended to, the text.

A new, and I hope valuable, feature is the Index, which I have tried to make copious and useful, to the student and to the tuner alike.

William Braid White.

Chicago, 1917.

ERRATUM

Page 300. For "Sectional View of Double-valve Action" read "Sectional View of Single-valve Action."

OMIT the following words:

5a Secondary Pouch.
7a Secondary Reduced Pressure Chamber.
8a Secondary Valve.
11 Primary-Secondary Channel.

Contents

Contents

Chapter I.

MECHANICS OF THE MUSICAL SCALE.

He who undertakes to master the art of piano tuning must have some acquaintance, exact rather than comprehensive, with that general body of knowledge known as Acoustics. This term is used to designate the Science of the phenomena known as Sound. In other words, by the term Acoustics we mean the body of facts, laws and rules which has been brought together by those who have systematically observed Sound and have collected their observations in some intelligible form. Piano Tuning itself, as an Art, is merely one of the branches of Practical Acoustics; and in order that the Branch should be understood it is necessary to understand also the Trunk, and even the Root.

But I might as well begin by saying that nobody need be frightened by the above paragraph. I am not proposing to make any excursions into realms of thought too rarefied for the capacity of the man who is likely to read this book. I simply ask that man to take my word for it that I am going to be perfectly practical and intelligible, and in fact shall probably make him conclude that he has all along been a theorist without knowing it; just as Molière's M. Jourdain discovered that he had been speaking prose all his life without knowing it. The only difference has been that my reader has not called it "theory." He has called it "knowing the business."

Anyhow, we are going to begin by discovering something about Sound. We are in fact to make a little excursion into the delectable kingdom of Acoustics.

What is Sound? When a street-car runs over a crossing where another line intersects, we are conscious of a series of grinding crashes exceedingly unpleasant to hear, which we attribute perhaps to flat tires on the wheels or to uneven laying of the intersecting trackage. The most prominent feature of such a series of noises is their peculiarly grating and peculiarly spasmodic character. They are on the one hand discontinuous, choppy and fragmentary, and on the other hand, grating, unpleasant to the hearing, and totally lacking in any but an irritant effect. These are the sort of sounds we speak of as "noise."

In fact, lack of continuity, grating effect and general fragmentariness are the distinguishing features of noises, as distinguished from other sounds.

If now we listen to a orchestra tuning up roughly off-stage, the extraordinary medley of sounds which results, may—and frequently does—have the effect of one great noise; although we know that each of the single sounds in the uproar is, by itself, musical. So it appears that noises may be the result of the chance mixture of many sounds not in themselves noises, but which may happen to be thrown together without system or order. Lack of order, in fact, marks the first great distinction between noises and other sounds.

If now we listen to the deep tone of a steamer's siren, or of a locomotive whistle, we are conscious of a different kind of sound. Here is the immediate impression of something definite and continuous, something that has a form and shape of its own, as it were, and that holds the same form so long as its manifestation persists. If, in fact, we continue to seek such sounds, we shall find that what are called Musical Sounds are simply more perfect examples of the continuity, the order and the definite character which we noticed in the locomotive whistle's sound. The more highly perfected the musical instrument, the more perfectly will the sounds evoked by it possess the qualities of continuity, order and definite form.

Continuity, persistence and definiteness, then, are the features which distinguish Musical Sounds from Noises. And there are therefore only two kinds of sounds: musical sounds and noises.

Now, what is Sound? The one way in which we can know it, plainly, is by becoming conscious of what we call the Sensation of Sound; that is, by hearing it. If one considers the matter it becomes plain that without the ability to hear there would be no Sound in the world. Sound cannot exist except in so far as there previously exist capacities for hearing it. The conditions that produce Sound are obviously possible, as we shall soon see, to an interminable extent in all dirccitions; yet what we may call the range of audible Sound is very small indeed. We can hear so very little of the conceivably hearable material; if I may use so rough an expression.

So it becomes quite plain that Sound cannot be considered as something in itself, existing in the sounding body apart from us, but must rather be

vibration. If I examine them under a microscope I shall perhaps be able to detect an exceedingly rapid vibratory motion. In order however to make sure of the existence of these unseen vibrations, it is only necessary to obtain a sheet of glass and smoke one surface of it by passing it over the flame of a candle. Then let a tuning fork be fitted with a very light needle point stuck on the end of one prong with a bit of wax, in such

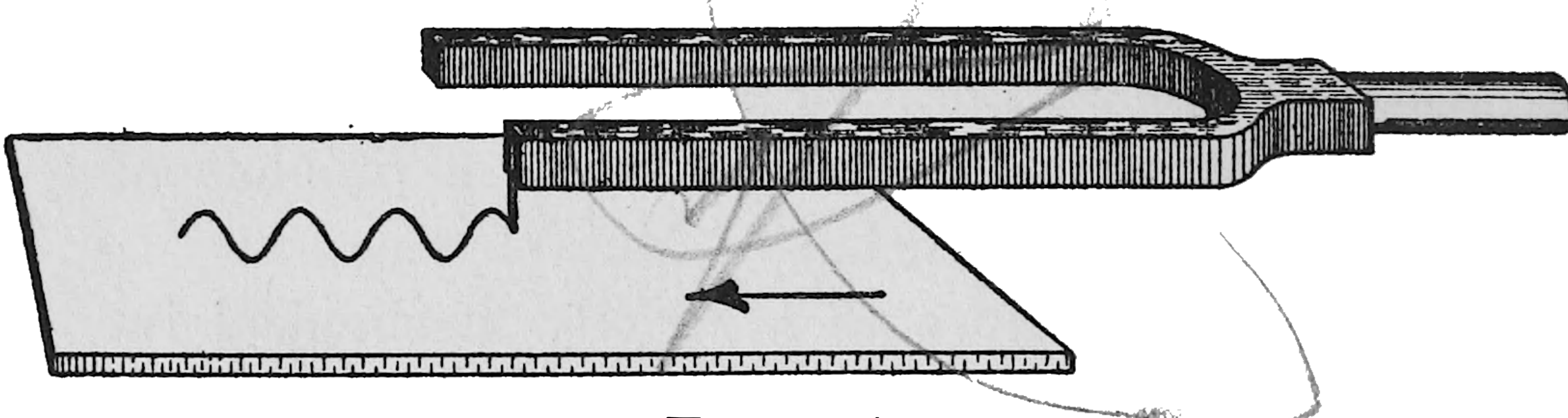


FIGURE 1.

a position that if the sheet of glass be placed parallel with the length of the fork, the needle point will be at right angles to both.

Now set the fork to sounding, and hold it so that the needle point lightly touches the smoked surface. Have a second person then move the sheet of glass lengthwise while the fork is held still. At once the needle-point will trace out a continuous wavy line, each wave being of that peculiar symmetrical form known technically as a curve of sines or sinusoidal curve. By adjusting the experimental apparatus with sufficient exactness it would be possible to find out how many of these little waves are being traced out in any given time. Each of these waves corresponds to one vibration or pendulum-like back and forth motion of the fork. By examining the wavy line with close attention, we shall see that if the motion of the glass sheet has been uniform, each sinusoid is identical in size with all the others, which indicates that the vibrations are periodic, that is to say, recur at regular intervals and are of similar width or amplitude.

We may therefore conclude from this one experiment that the physical producer of musical sound is the excitation of the sounding body into periodic vibrations.

Listen to the noise of the machinery in a saw mill. When the circular saw starts to bite at a piece of wood you hear a series of grating cracks, which almost instantly assume the character of a complete definite musical sound, though rough in character. As the saw bites deeper into the wood the sound becomes first lower, then higher, until it mounts into a regular song. As the saw comes out through the wood the sounds mount quite high and then instantly die away. What is the cause of this phenomenon?

The circular saw is a steel wheel with a large number of teeth cut in its circumference. Suppose there are fifty such teeth. At each revolution of the wheel, then, each tooth will bite the wood once. If the wheel revolves at the rate of say four revolutions per second, it follows that there will be four times fifty or two hundred bites at the wood in this time. That means that the wood will receive two hundred separate scrapes per second. Hence, the rotation of the wheel will be slightly interrupted that number of times in one second. Hence, again, the surface of the air around the wheel will be vibrated back and forth just as many times, because the entry and emergence of each tooth will cause an alternate compression and suction on the air around it. Try another experiment. Stand five boys up in a row one behind the other, so that each boy has his outstretched hands upon the shoulders of the boy in front of him. Push the last boy. He falls forward, pushes the next and regains his position. Next falls forward, pushes Third and regains his position. Third falls forward, pushes Fourth and regains his position. Fourth falls forward, pushes Fifth and regains his position. Fifth has no one in front of him and so falls forward without being able to regain his position. In this way we illustrate the compression and rarefaction of the air by the alternate fallings forward and regainings of position undertaken by the boys. The air is even more elastic than the boys and so forms these waves of motion which we saw traced out by the stylus on the tuning fork.

Now, it is plain that as the rotation of the circnlar saw increases in speed the pulses become sufficiently rapid to fuse into one continuous musical sound. If the saw were rotated at irregular, constantly shifting speed, the separate shocks would not coalesce and we should have merely the sensation of a discontinuous, fragmentary, grating series of shocks which we should call a noise. Thus again we see that regularly recurring motions of the sounding body are requisite to produce musical sounds.

Transmission of Sound. But the illustration of the five boys (which is due to the late Professor Tyndall, by the way) shows something further. It shows first how the excitation of a body into vibration at regular intervals produces an effect upon the immediately surrounding air, causing it in turn to oscillate back and forth in pulses of alternate compression and rarefaction. But it shows more. It shows that the sound-motion, as we may call it, is transmitted any distance through the air just as the shock started at one end of the row of boys is felt at the other end, although each boy moves only a little and at once recovers

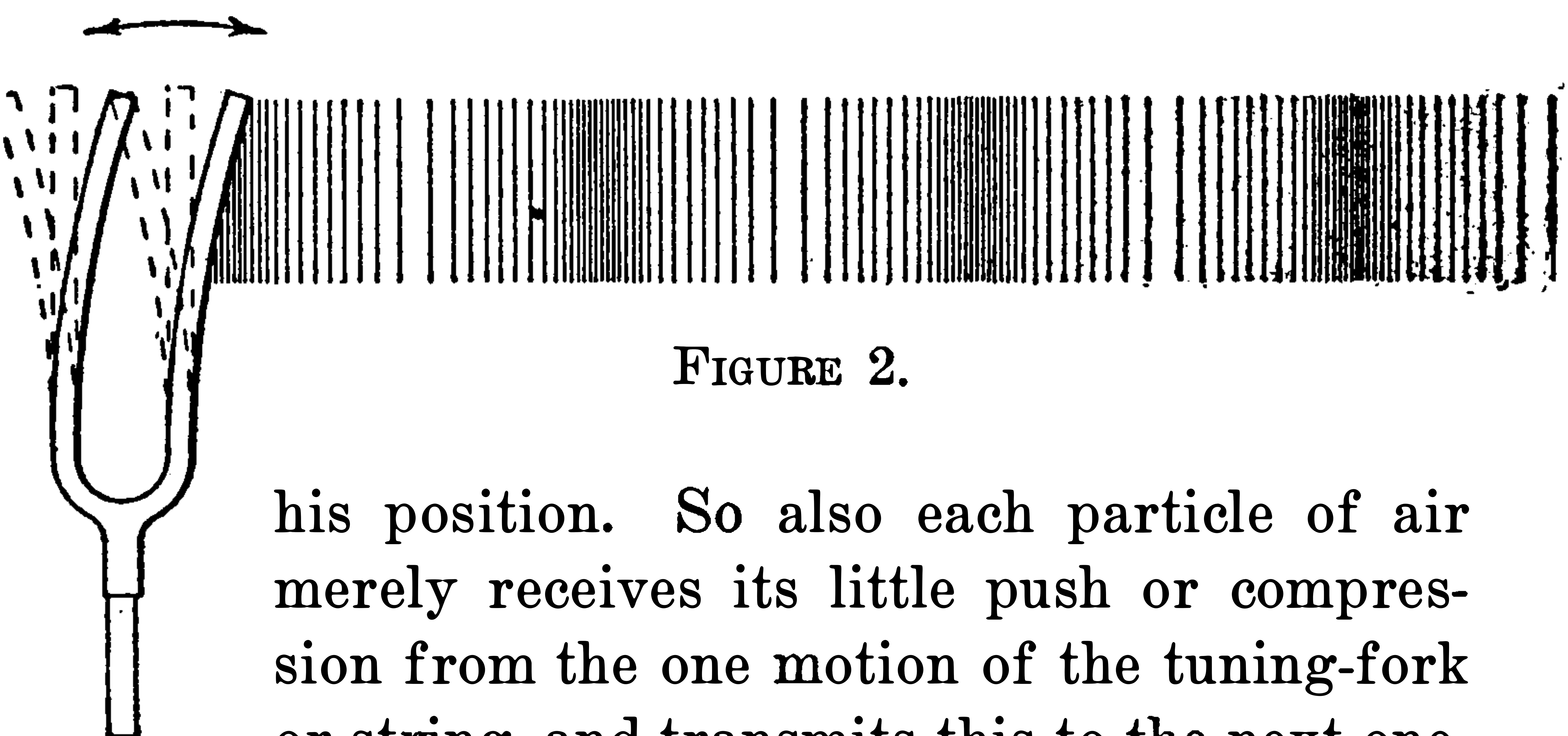


FIGURE 2.

his position. So also each particle of air merely receives its little push or compression from the one motion of the tuning-fork or string, and transmits this to the next one. At the backward swing of the tuning-fork or string the air particle drops back to fill up the partial vacuum it left in its forward motion, whilst the motion transmitted to the second particle goes on to the third and to the fourth and so on to the ear of the hearer. Yet each particle has merely oscillated slightly back and forth.

Now, this mode of transmission evidently depends upon the existence of an atmosphere. In fact, we can soon show that, apart from all question of ears, Sound could not exist for us, as we are in this state of existence, without an atmosphere. Let an alarm-clock be set to ringing and then placed under the glass bell of an air-pump. We now begin to displace the air therefrom by working the handle of the pump. As the quantity of air inside the bell thus becomes smaller and smaller, the sound of the alarm-clock's ringing becomes fainter and fainter, until, where the air is at a certain point of rarefaction, it entirely disappears; although the clapper of the alarm will still be seen working. In other words, there must be an atmosphere or other similar medium, like water, for transmission of the sound-motion from the excited body to the ear.

Properties of Musical Sounds. Having arrived at this point, we are now in a position to discuss musical sounds in general and to discover the laws that govern their behavior. The first principle we shall lay down is that musical Sounds are distinguished from noises by the continuity of their sensation; or in other words, musical sounds are evoked by *periodic* vibrations. It is thus possible to measure the frequency of vibration that evokes a sound of some given height; in other words to determine its pitch.

It is also possible, as we shall see, to determine a second quality of musical sounds; namely, their relative loudness or softness, or, as we shall call it, their intensity.

Lastly, we can discover differences in character or quality between musical sounds, and we shall see also that it is possible to measure these differences accurately.

Loudness. Let us begin with the second quality mentioned; that of loudness or intensity. If a tuning-fork be excited by means of a violin bow and then examined through a microscope while its motion persists, it will be observed that as the sound dies away, the amplitude or width of swing of the prongs is becoming less and less, until the cessation of motion and of the sound occur together. If, whilst the sound is thus dying away, the fork is again bowed, the amplitude of the prong's motion again is seen to increase just as the sound increases. In fact, it has been found by authoritative experiments that not only does the loudness of a sound vary with the amplitude of the vibrations of the sounding body; but exactly as the square of the amplitude. For in-

loud as one heard at a distance of twice fifty, or one hundred feet. However, it must also be remembered that the situation of the sounding body and of the hearer in proximity to other objects, has a modifying effect upon the loudness of sound as perceived. In fact, we shall see that this is only part of the truth expressed in the term "resonance," about which we shall have something to say later on.

Pitch. Without making any special attempt at producing an ideal definition of "pitch," it will be enough to call it the relative acuteness or gravity of a musical sound. Everybody knows what is meant by saying that a musical sound is high or low. The province of Acoustics lies in finding some measuring-rule, some standard, whereby we can measure this lowness or highness of a sound and place it accurately in relation to all others. The whole system of music is built upon simply a measure of pitch, as we shall see.

Now, first of all, let us find out what it is that makes a sound high or low. In other words, what is the mechanical reason for a sound producing a sensation of highness or lowness?

Musical sounds are produced through the periodic continuous vibration of some body. In the experiment of the circular saw, to which I directed attention some pages back, it was pointed out that as the speed of the saw increases, so the musical sound produced through its contact with the wood rises in height. This may be verified by any number of experiments that one chooses to make, and the net result is the fact that the pitch of musical sounds depends upon the number of vibrations in a given unit of time performed by the sounding body. Let us put it in a formula, thus:

The pitch of a musical sound varies directly as the number of vibrations per unit of time performed by the sounding body: the greater the number of vibrations, the higher the pitch.

Unit of Time. It is customary to assign the second as the unit of time in measuring frequency of vibrations, and in future we shall use this always. If, therefore, we speak of a certain pitch as, say, 500, we shall mean 500 vibrations per second.

Double Vibrations. In counting vibrations, we understand that a motion to *and* fro constitutes one complete vibration. A motion to *or* fro would be merely a semi-vibration or oscillation. In the United States and England it is customary to imply a double vibration (to and fro) when speaking of a "vibration." In France the single or semi-vibration is the unit of measurement, so that the figures of pitch are always just double what they are as reckoned in the English or American style.

Range of Audibility. It is found as the result of experiment that the human sense of hearing is distinctly limited. The lowest tone that can be distinctly heard *as a musical sound* is probably the lowest A (A_{-1}) of the piano which, at the standard international pitch, has a frequency of 27.1875 vibrations per second. Sounds of still lower frequency may perhaps be audible, but this is doubtful, except in the cases of persons specially trained and with special facilities. In fact, any specific musical sounds lower than this probably do not exist for human beings, and when supposed to be heard, are in reality not such sounds at all, but upper partials thereof.[1] The 64-foot organ pipe, which has occasionally been used, nominally realizes tones lower than 27 vibrations per second, but these are certainly not audible as specific separate sounds. They can and do serve perhaps as a bass to reinforce the upper partials of the pipe or the

[1] See Chapter II.

upper tones of a chord; but they do not appear as separate sounds, simply because the ear does not realize their pulses as a continuous sensation, but separates them. In fact, we may feel safe in concluding that the lowest A of the piano is the lowest of musical sounds generally audible. This statement is made in face of the fact that the sound evoked by the piano string of this note is usually powerful and full. This only means, however, that the sound we hear on the piano is not the pure fundamental vibration of 27.1875 vibrations per second, but a mixture of upper partials re-inforced by the fundamental. Of these partials we shall have to speak later, for they are of vital importance to the due consideration of our subject-matter.[1]

A similar limitation confronts us when we come to the highest tones audible by the human ear. Here again there is considerable diversity of opinion as well as of experience. The highest note of the piano, C_7, has a frequency of 4,138.44 vibrations per second at the international pitch. However, there is no special difficulty in hear-

[1] For a very interesting discussion of the whole question of deepest tones, I refer the reader to Helmholtz, "Sensations of Tone," third English edition, Chapter IX.

ing sounds as much as two octaves higher, or up to 16,554 vibrations per second. Above this limit, comparatively few people can hear anything, although musicians and acousticians have been able to go much higher.[1]

The Musical Range. The limits of audibility therefore embrace eleven octaves of sounds, but the musical range is considerably smaller. The modern piano embraces virtually the complete compass of sounds used in music, and, as we all know, that range is seven octaves and a minor third, from A_{-1} to C_7.

Let it be noted that if the range of hearable sounds lies between, say 27 and 32,000 vibrations per second, the number of possible distinct musical sounds is enormous. We know that it is quite possible for the trained ear to discriminate between sounds which, at the lower end of the gamut anyhow, are no more than 4 vibrations per second apart. For many years the late Dr. Rudolph Koenig of Paris, one of the most gifted acousti-

1 Many years ago, before I had become practically interested in Acoustics, and when my ear therefore was in every sense untrained, I was tested by the Galton whistle up to 24,000 vibrations per second, which is near G_9, two and one-half octaves above the piano's highest note. This is well up to the higher limit of most trained ears, although some acousticians have tuned forks running up to C_{10}, with 33,108 vibrations per second.

cians the world has ever known, was engaged in the construction of a so-called Universal Tonometer, consisting of a superb set of one hundred and fifty tuning forks, ranging in frequency from 16 to 21,845.3 vibrations per second. In this remarkable instrument of precision, the lowest sounds differ from each other by one-half a vibration per second, while within the musical compass the difference never exceeds four vibrations. It can readily be seen therefore that the number of possible musical sounds is very much greater than the eighty-eight which comprise the musical gamut of the piano.

Just how the musical scale, as we know it, came to be what it is, I cannot discuss here; for the simple reason that the whole question is really to one side of our purpose.[1] Whatever may be the origin of musical scales, however, we know that the diatonic scale has existed since the twelfth century, although the foundation of what we call modern music, employing the chromatic tempered

1 The claims made for the eleventh century monk, Guido d'Arezzo, have been disputed, and the reader who is interested in the historical aspect of the subject is referred to Grove's "Dictionary of Music and Musicians," to Helmholtz' "Sensations of Tone," and to A. J. Ellis' "History of Musical Pitch," quoted in Appendix 20 of his translation of Helmholtz (3rd edition).

scale, was rightly laid only by Sebastian Bach, who died 1750. Music is a young, an infantile, art, as time goes.

The Diatonic Scale. We have already seen that the musical tone is a fixed quantity, as it were, being the sensation that is produced or evoked by a definite number of vibrations in a given time. This being the case, it becomes evident that all possible tones must bear mathematical relations to each other. As long ago as the sixth century B. C. the Greek philosopher and scientific investigator Pythagoras propounded the notion that the agreeableness of tones when used with each other is in proportion to the simplicity of their mathematical relations. Now, if we look at the scale we use to-day we find that although the relations of the successive members of it to each other appear to be complex, yet in fact these are really most simple. Let us see how this is:

Unison. We all know that we can recognize one single tone and remember it when we hear it a second time. If now we draw the same tone from two sources and sound the two tones together, we find that they blend perfectly and that we have what we call a Unison. If we were to designate

as the next closest relation what is called the Fifth. If one strikes simultaneously the keys C—G upwards on the piano one observes that they blend together almost as perfectly as the tones C—C or G—G, or any other octave or unison. The Interval or relation thus sounded is called a Perfect Fifth. When we come to trace up its acoustical relations we find that a tone a Fifth above any other tone is produced by just one and a half times as many vibrations in a given time as suffice to produce the lower tone. Thus we can place the mathematical relation of the interval of a Perfect Fifth as $1:1\frac{1}{2}$, or better still, for the sake of simplicity, as $2:3$, which is the same thing. So we now have the simplest relation that can exist between *different tones;* the relation of the Perfect Fifth or $2:3$. This important fact will lead to essential results, as we shall see.

The Natural Scale. This interval, the Fifth, will be found competent to furnish us with the entire scale which the musical feeling and intuition of men have caused them, throughout the entire Western World at least, to accept as the basis of music and of musical instruments; that is to say, the diatonic scale. If we begin with the tone C at any part of the compass and take a series of Fifths upwards we shall arrive at the following scale:

C G D A E B F sharp.

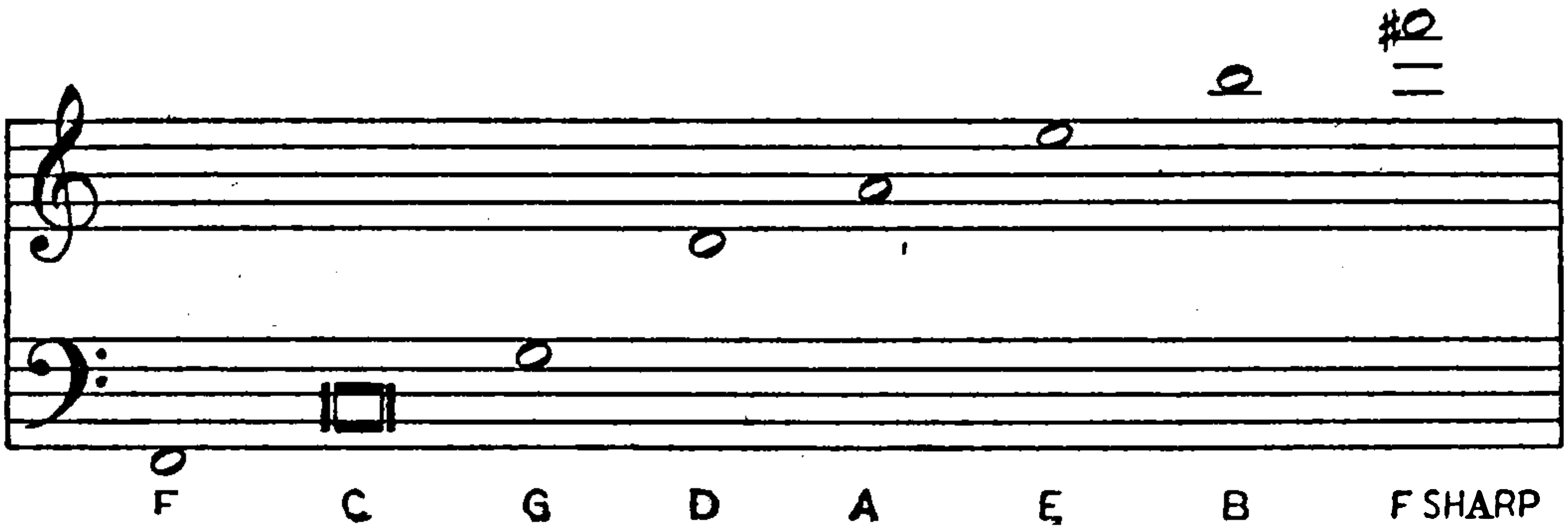


FIGURE 3.

These tones of course are spread over a compass of five octaves, but if they are drawn together into the compass of one octave, as they may rightly be drawn (see *supra* "The Octave") then we shall have a scale like this:

C D E F sharp G A B

Now the F sharp in the present case is not actually used, but instead we have F natural, which in fact is drawn from the interval of a Perfect Fifth *below* the key-tone C. The reason for this preference of F natural over F sharp lies in the fact that the diatonic scale is thereby given a certain symmetry of sound which otherwise it would lack and because the work of practical musical composition is advantaged by the substitution.[1]

The Diatonic Scale. We have arrived now at the Diatonic Major Scale and although we need not here be concerned with the origin thereof, we may be satisfied to know that it appears to satisfy the musical needs of civilized mankind. Let us again examine the series of tones, this time including the octave to C, whereby we in reality complete the *circle of Fifths,* as it may be called, and return to the key-tone, for the octave is the same for musical purposes as the Unison. We have then, counting upwards,

C D E F G A B C

which we can readily identify as the series of seven white keys on the piano; with the eighth following and beginning a new series or scale. The complete diatonic scale, when founded on the tone C, may thus be seen, merely by looking at the piano, to consist of a series of such scales, seven

1 For a general discussion of these reasons consult Goetschius' "Theory and Practice of Tone-Relations."

in all, following one another from one end of the piano to the other.[1]

Relations. Now, if we go a step further and discover the relations which these tones hold to each other mathematically, when brought together into one octave, we find them to be as follows, expressing the lower C as 1 and the upper C as 2, and counting upwards always:

C	D	E	F	G	A	B	C
1	9/8	5/4	4/3	3/2	5/3	15/8	2

Or in other words, the relation C to D is the same as the ratio 8 to 9. The relation C to E is likewise 4 to 5. The relation C to F is 3 to 4, C to G is 2 to 3, C to A is 3 to 5, C to B is 8 to 15 and C to its octave is 1 to 2.

Tones and Semitones. Now if we glance at the C scale as shown on the white keys of the piano we shall see that it exhibits some interesting peculiarities. Between each pair of white keys, such as C—D or D—E, is a black key, which most people know is called a sharp or a flat. But between E—F and B—C is no space whatever, these pairs of white keys being immediately adjacent to each

[1] Note, however, that the modern piano contains three tones lower than the lowest C, making a minor third more of compass.

other. If we run over the keys to sound them we shall find that the sound-interval between E—F or B—C can at once be heard as being closer or narrower, as it were, than the sound-interval between A—B or C—D or D—E, or F—G or G—A or A—B. The longer intervals, between which we find the black keys, are called Diatonic Whole Tones, and the shorter intervals E—F and B—C are called Diatonic Semitones.

Diatonic Relationships. The exact relations subsisting between the steps or degrees of the Diatonic Scale can be ascertained by dividing the ratios previously had, by each other, pair to pair. Consulting the table previously given (*page* 25) showing the relations of the steps to their key-tone, we find that when the ratios are divided pair by pair we get the following relations between each pair of notes:

C.....D....E..F.....G....A.....B..C,

8:9 9:10 15:16 8:9 9:10 8:9 15:16

Now the first thing that will be observed is that there are three intervals here, not two. There are in fact, evidently two kinds of whole-step or whole-tone. For it is evident that the sound-distance between C and D is more than the sound-distance between D and E. In actual fact, these two whole-steps must be recognized as distinct. This, however, brings about an entirely new condition and one quite unsuspected. For inasmuch as the Diatonic Scale must of course always retain the same relationships among its successive steps, it is evident that this idea of two different kinds of whole-step must land us in difficulties.

The trouble is that we cannot always play in the key of C, by which I mean that sometimes, in fact very often, we desire to build our music upon Diatonic Scales which are founded upon other tones than C. From the point of view towards which I am leading—namely, that of tuning—we see here a serious difficulty, for it is at once evident that if we undertake to tune a Diatonic Scale, as suggested some time back, by considering it as a series of Perfect Fifths, we shall find ourselves in deep water as soon as we quit the key of C. Let me make this plainer.

Understand first of all that we have as yet talked only of a scale founded on C and therefore including what are known simply as the white keys or natural notes. Suppose we begin by tuning a series of fifths quite perfect from some given C, say for the sake of convenience a C of which the pitch is 64 vibrations per second. This is a little less than the pitch of C would be at the International standard but is more convenient for purposes of calculation.

Then we should get a result like this:

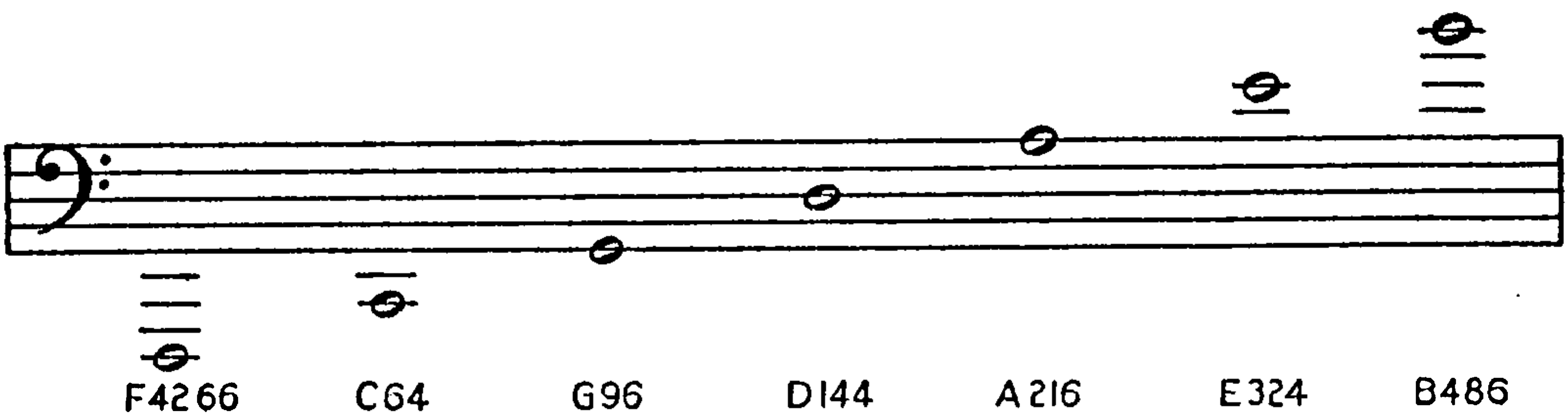


FIGURE 4.

Now, let us reduce this down to one octave, by transferring the higher tones down, through the simple process of dividing by 2 for each octave of transference down and multiplying by 2 for each octave of transference up. This will give us the following result:

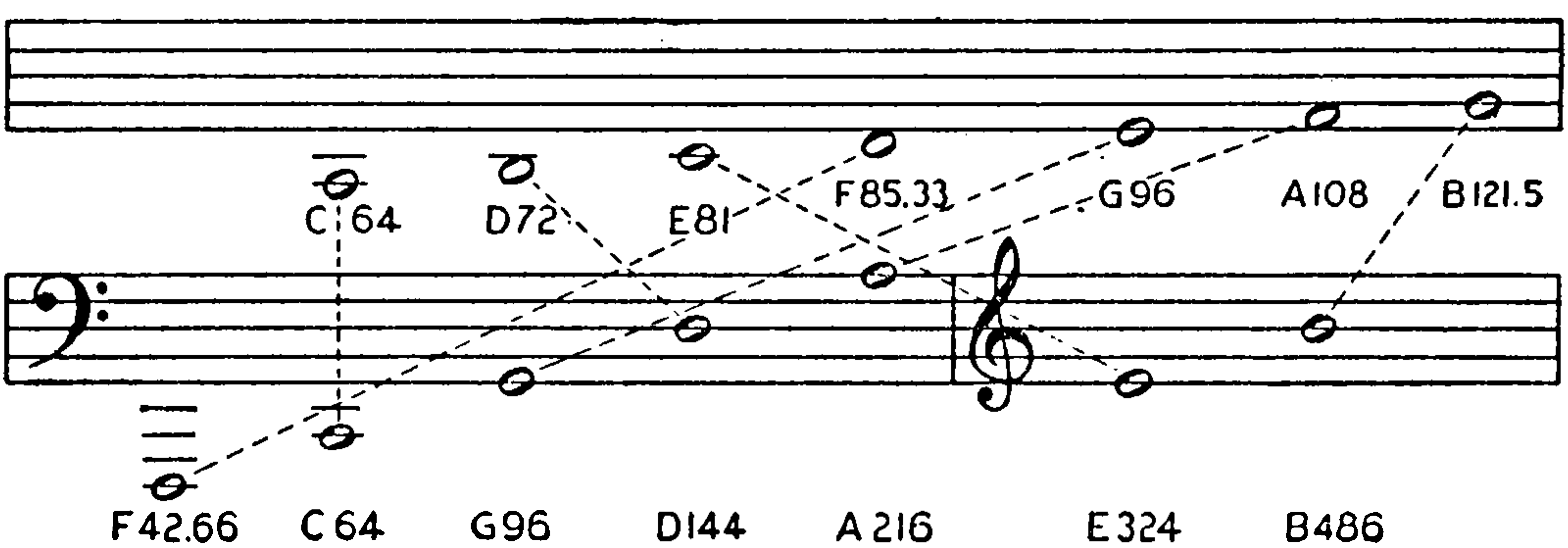


FIGURE 5.

octave we have F♯ 182.25. C♯ is a Perfect Fifth above F♯ and so will be 546.75, or, dropping an octave, 273.375. Now, we can construct a scale of D as follows, beginning with the D 144 that we already have, using all the other notes already provided and the two new ones besides. That gives us:

D_2	E_2	$F♯_2$	G_2	A_2	B_2	$C♯_3$	D_3
144	162	182.25	192	216	243	273.375	288

If you will look at it closely you will see that there must be something wrong. The distance between F♯ and G seems small, and so does the distance between C♯ and D. To test the thing, let us now construct a diatonic scale on the ratios we know to be correct [1] and see what results we get. It works out as follows:

D_2	E_2	$F♯_2$	G_2	A_2	B_2	$C♯_3$	D_3
144	162	180	192	216	240	270	288

Ratios

8:9 9:10 15:16 8:9 9:10 8:9 15:16

Now, just for purposes of comparison, let us put these two scales together, one below the other. They look like this:

[1] See page 25 et seq.

SCALE MADE UP FROM C SCALE AND PERFECT FIFTHS TUNED THEREFROM

D	E	F♯	G	A	B	C♯	D
144	162	182.25	192	216	243	273.375	288

SCALE MADE UP FROM KNOWN DIATONIC RATIOS

144	162	*180*	192	216	*240*	*270*	288

At once it can be seen that the F♯ and the C♯ which we manufactured by the perfectly legitimate method of tuning perfect Fifths from the nearest tone available in the scale of C, are both wrong when secured in this way. Also, it can be seen that the B which belongs to the scale of C will not do for the scale of D. Not only is this so, but if the experiment is made with other key-tones, it will be found that they all, except the scale of G, differ somewhere and to a greater or less extent from the scale of C, even with reference to the notes which they have in common with C.

True Intonation. It is evident, therefore, that no method of building up diatonic scales by tuning pure intervals, will do for us if we are going to use the same keys and the same strings for all the scales we need. It is evident, in fact, that if we tune perfect Fifths or any other intervals from C or any other key-tone and expect thereby to gain a scale that will be suitably in tune for all keys in which we may want to play, we shall be disappointed. Not only is this so, but it must be remembered that so far we have not attempted to consider any of the so-called sharps and flats, except in the one case where we found two sharps in the scale of D, properly belonging there. It turns out, however, when we investigate the subject, that the sharp of C, when C is in the scale of C, is quite a different thing, for instance (as to pitch), from the C♯ which is the leading tone of the scale of D.

Chromatic Semitone. The *chromatic semitone,* which found its way into the scale during the formative period of musical art—mainly because it filled a want—is found upon investigation to bear to its natural the ratio $^{24}/_{25}$ or $^{25}/_{24}$, according as it is a flat or a sharp. In the case we have been considering, then, whilst C♯ as the leading tone in the scale of D has a pitch, in true intonation, of 270, the C♯ which is the chromatic of C 256 (see previous tables) would have a pitch of $256 \times {}^{25}/_{24}$ or 266.66. Similar differences exist in all cases between chromatic and diatonic semitones, thus introducing another element of confusion and impossibility into any attempt to tune in true intonation.

Derivation of chromatic ratio. Actually the chromatic semitone is the difference between a $^{10}/_{9}$ ratio whole tone or *minor tone* as it is often called, and a diatonic semitone; thus $^{10}/_{9} \div {}^{16}/_{15} = {}^{25}/_{24}$.

The Comma. The difference between the $^{9}/_{8}$ (major) and the $^{10}/_{9}$ (minor) tones is called a *comma* $= {}^{81}/_{80}$. This is the smallest musical interval and is used of course only in acoustics. ($^{9}/_{8} \div {}^{10}/_{9} = {}^{81}/_{80}$).[1]

Musical Instruments Imperfect. The above discussion, then, leads us to the truth that all musical instruments which utilize fixed tones are uecessarily imperfect. As we know, the piano, the organ and all keyed instruments are constructed on a basis of seven white and five black keys to each octave, or as it is generally said, on a 12-to-the-octave basis (13 including the octave note). If now we are to play, as we of course do play, in all keys on this same key-board, it is evident that we cannot tune pure diatonic scales. The imperfection here uncovered has, of course, existed ever since fixed-tone musical instruments came into being. The difficulty, which has always been recog-

1 The diatonic minor scale is affected equally by this argument; but has not been mentioned here for reasons set forth in Chap. III.

nized by instrument builders and musical theorists, can be put succinctly as follows:

The piano and all keyed instruments are imperfect, in that they must not be tuned perfectly in any one scale if they are to be used in more than that one scale. Hence a system of compromise, of some sort, must be the basis of tuning.

The violins and violin family, the slide trombone and the human voice can of course sound in pure intonation, because the performer can change the tuning from instant to instant by moving his finger on the string, modifying the length of the tube or contracting the vocal chords. When they are played, however, together with keyed instruments, the tuning of these true intonation instruments is of course modified (though unconsciously), to fit the situation.

All tuning imperfect. All tuning, therefore, is necessarily imperfect, and is based upon a system called "Temperament." This system is described and explained completely in the third and fourth chapters of this book.

Temperament. I have taken the reader through a somewhat lengthy explanation of the necessity for Temperament on the notion that thereby he will be able to understand for himself, from the beginning, the necessity for doing things that otherwise would seem illogical and inconsistent. The peculiar kind of tuning that the piano tuner must do would seem in the highest degree absurd if the student did not understand the reasons for doing what he is taught to do. Seeing also that this correct knowledge is seldom given by those who teach the practical side of the art, I thought it better to go into some detail. In any case, it is well to realize that no man can possibly be a really artistic piano tuner unless he does know all that is contained in this chapter and all that is contained in the next three. It is worth while therefore to be patient and follow through to the end the course of the argument set forth here.[1]

1 A complete discussion of the problem of True or Just Intonation is to be found in the classic work of Helmholtz, to which the reader is referred. See especially Chapter XVI, Appendices 17 and 18 and the famous Appendix 20, composed by the English translator, A. J. Ellis. My own "Theory and Practice of Pianoforte Building" contains (Chapter VI) a useful discussion of the Musical Scale and Musical Intonation.

CHAPTER II.

ON THE VIBRATION OF A PIANO STRING.

Of all sounding bodies known to music, the musical string is without doubt the most common, the most easily manipulated for musical and mechanical purposes, and the most efficient. Acquaintance with ascertained facts as to the behavior of musical strings under practical conditions is necessary for the complete equipment of the piano tuner; although this acquaintance need not be exhaustive, so long as it be, to its extent, exact. Avoiding mathematical symbols which, requisite as they are to a comprehensive study of Acoustics, may nevertheless be beyond the familiarity of most of those who will read this book, I shall here briefly investigate certain properties of musical strings and especially of the piano string. The discussion, I can promise, need seem neither dry nor uninteresting.

The String. To be exact, a string should be defined as a perfectly flexible and perfectly uni-

ical sounds owe their existence to the fact that some solid body is thrown into a state of periodic vibration. The kind of vibration can best be explained by likening it to the swing to and fro of a pendulum. A pendulum is fixed at one end and tends naturally to swing back and forth on its pivot. The kind of vibration which the pendulum performs is called simple or pendular vibration. The tuning fork, when set in vibration, is also very much the same thing as a pendulum, since one end of each prong is fixed and the other end can therefore swing freely. The tuning fork furnishes, when excited, an excellent practical example of simple or pendular vibration of sufficient rapidity to produce musical sound.

Tones of the Piano String. Go to a piano and strike one of the low bass keys in the octave between A_{-1} and A. These very low keys operate on single strings only and hence are excellently adapted for our purpose.[1]

Strike on the piano the key (say) F. Hold the

1 Incidentally, let me say that the piano is an almost complete ready-made acoustical instrument for the investigation of the phenomena of musical strings, sympathetic resonance, beats and beat-tones, and partials. With a piano at hand the student can dispense with all experimental means except the tuning-fork. I shall suppose that a piano is at hand during the reading of this and other chapters.

key down, and listen carefully. At first you will hear simply the full sonorous tone F, deep and solemn. But listen closely, repeating the experiment till the ear becomes familiar, and you will gradually observe that, mingled with the original sound F, there are a number of other sounds, apparently very closely related to the original, coloring it rather than altering its pitch, but at the same time recognizable as sounds that spring from a different level. By repeating the experiment with various of these low strings (or by going higher and taking care that one string in the two-string unisons is damped off), you will gradually be able to perceive the remarkable fact that every piano string produces a sort of compound tone, consisting primarily of its natural tone or fundamental, as we may call it, but containing also the octave thereto, the fifth above that and the second octave. It is true that these extra sounds are feeble and can be heard only by means of practice and the exercise of patience; but heard they can be, more and more clearly as one's familiarity with the process grows.

Partial Tones. The truth is that the piano string does not evolve a simple but an exceedingly complex musical tone. Not only the three extra tones of which I spoke before can be proved to exist, but in fact an immense number of other tones, all bearing given harmonic relations to the fundamental, can be shown to be evoked, and by the use of suitable apparatus can be detected and isolated, one by one, through the sense of hearing. Special resonators have been made which enable the hearer to detect these partial tones clearly.

Even without such special apparatus, however, we can detect a number of the partial tones if we take advantage of the piano's property of sympathetic resonance; a property imparted by the sound-board.

Sympathetic Resonance. Hold down the middle C key, without striking the string. Then, while holding the key down, strike a powerful blow on the C immediately below. When the sound has swelled up, let go the lower key whilst holding on to the upper or silently pressed key. At once the sound of middle C floats out of the silence, pure and ethereal. What is the cause of this sound? How has the middle C string been excited? The answer is found in the fact that the lower string which was struck, not only produces its fundamental tone but also evokes its octave above. The peculiar sort of vibration of the C_2 string which produced this octave is resonated through the sound-board and reproduced on the middle-C string. In the same way, the twelfth (G_3) can be brought out, and so can the next octave C_4. In fact, with a very good piano and by choosing a low enough sound for the fundamental, even higher partial tones can thus be brought out by sympathetic resonance from the original string to the string corresponding with the true pitch of that partial.[1]

Complex String Vibration. Thus we learn that the piano string vibrates as a complex of vibrations, not as one simple form of vibration; for it is evident that if the string evokes, as we know it does, a complex of sounds, these must arise from a complex of vibrations. Let us see how this is:

Turning again to the piano, select a string in such a position that it can be measured accurately as to its speaking length. A grand piano is most convenient for the purpose, and the string may be selected from the overstrung or bass section. Now accurately measure the speaking length of the string between bridges, and mark carefully

[1] For a further discussion of sympathetic resonance, see Chapter VII.

with a piece of chalk on the sound-board the exact middle point as near as you can determine it. Then sound the string and whilst holding down the key, touch the string at the middle point very lightly with a feather. If you perform the operation skilfully enough, you will find that instantly the fundamental tone of the string ceases and there floats out the octave above, quite alone and distinct.

Measure now one-third of the length, mark it, and again sound the string. Placing the feather carefully at the exact division point and damping the shorter segment with a finger, the fifth above the original sound is heard.

Automatic string division. What is the meaning of all this? Plainly in the first case it meant that the string naturally subdivides itself into two parts of equal length and that the vibration of either half gives the octave above the original. Thus we have two vitally important facts at our disposal, one relating to the form of vibration of the string and the other to the law of string length as proportioned to pitch.

Moreover, in the second case, if we allowed the ⅓ division of the string to vibrate, we should get from it a sound an octave above the sound of the longer or ⅔ division. Since we damped the shorter segment, however, we conclude that the fifth above the original sound was produced by a string length ⅔ of the original length. If we now continue our experiments we may find that ⅘ of the original length produces a major 3rd above the original sound, and that ¼ of the length produces a sound 2 octaves above the original sound. Plainly then, we have two great laws revealed. The first is:

When a string fixed at each end like the piano string, is struck at one end, it vibrates in a complex form, most strongly in its full length but also perceptibly in segments of that length such as ½, ⅓, ¼ and ⅕.

The second law is equally important. It may be stated as follows:

Length and Pitch. The pitch of a string—that is to say, the number of vibrations, per unit of time, it can perform, is proportional inversely to its length. Thus, since an octave above a given sound has twice as many vibrations per second as the original sound, it follows that to obtain a sound an octave above a given sound we must have a string one-half as long.

Weight, Thickness and Tension. Similar laws exist with regard to the influence upon string vibrations of weight, thickness and tension. Without undertaking to prove these completely, we may state them briefly as follows:

The frequency of a string's vibration is inversely proportional to the square root of its weight. In other words, if the weight be divided by 4 (the square of 2) the frequency will be multiplied by 2. To produce a tone one octave below its original tone, the weight of the string must be increased in the proportion 4:1. To produce a tone one octave above the original tone, the weight of the string must be only ¼ its original weight.

The frequency of string vibrations is directly proportional to the square root of their tension. In other words, to get twice as many vibrations, you must multiply the tension by $2^2 = 4$. To get four times as many vibrations you must multiply the tension by $4^2 = 16$. So if a string be stretched with a weight of 10 lbs. and it is desired to make it sound an octave higher, this can be done by making the stretching weight $(4 \times 10) = 40$ lbs.

The frequency of string vibrations is inversely proportional to the thickness of the string. If a string of a given length and weight produces a

fact, vibrate in this rather than in some other way. It is easy to talk about string subdivision and partial tones, but there is very little use in mouthing words that do not carry with them to our minds real meanings, or in talking about processes which we do not really understand. So, let us take the trouble to discover why a string vibrates as we have shown it to vibrate. Here again, the piano shall be our instrument of investigation.

The Wash-line Experiment. The first thing to realize when we begin to talk about string vibrations is that the vibration itself is merely the transmission of a motion from one end of the string to the other. This motion will continue until it is transformed into some other sort of energy or else is thrown out of its direction into another direction. Suppose that you take a long cord, like a wash-line. Obtain one as much as twenty feet long. Fasten one end to a post and stretch the cord out until you hold the other end in your hand with the entire length fairly slack. Now try to jerk the cord up and down so that you can get it to vibrate in one long pulse. That pulse will affect the entire length of the cord, which you will observe to rise from its plane of rest, belly out in a sort of wave, descend to the point of rest again, belly out once more on the opposite side and return to the point of rest, making a complete swing to and fro. Compare the illustration figure 6.

When you find that you can do this (practice is needed), try a different experiment. Try to jerk the cord with a sort of short sharp jerk so that, instead of vibrating in its whole length, a sort of

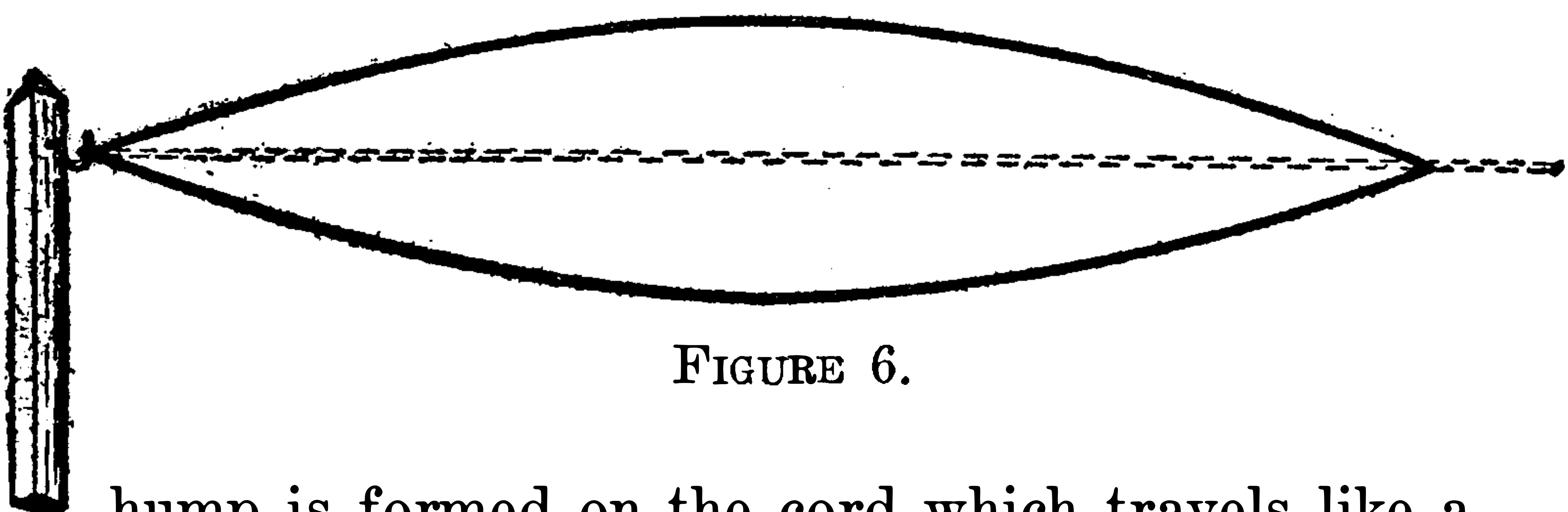


FIGURE 6.

hump is formed on the cord which travels like a wave through a body of water. This short wave will travel along the whole cord, as you will be able to see by watching it narrowly, until it comes to the end fixed on the post. At once you will see that the wave, instead of disappearing, is reflected back, reversing its direction of travel and also its position, being now on the opposite side of the cord. Thus reflected, the short wave travels back to you.

This is an example of what is called the *reflec-*

tion of a sound impulse. But it has a very important bearing on the general problem of piano string vibration, as we shall see.

Suppose that you are able to time your efforts so carefully that you can deliver a series of these short sharp jerks, forming these short waves, at the rate of one per second. If you time your impulses carefully, you will find that the second impulse will start away from your hand just as the

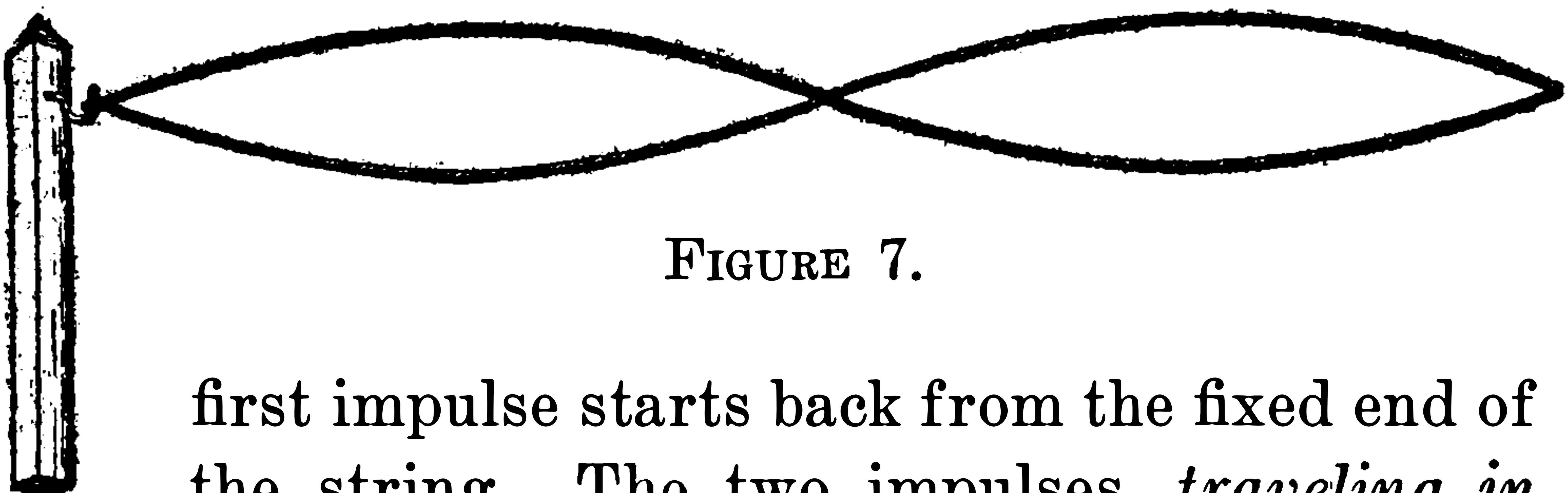


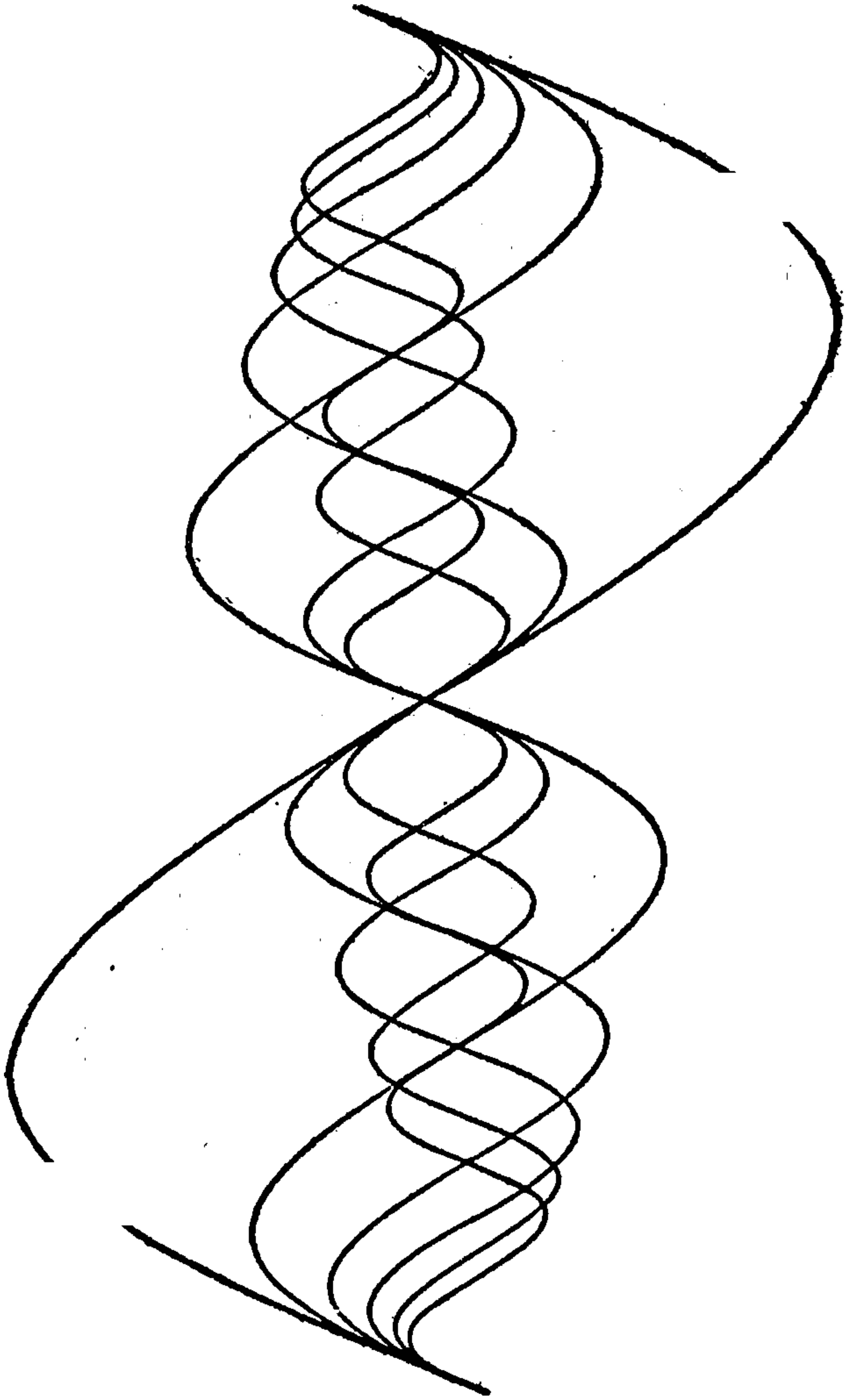
FIGURE 7.

first impulse starts back from the fixed end of the string. The two impulses, *traveling in opposite directions and in opposite phases of motion* (in positions on the cord opposite to each other), will meet precisely in the center, for neither one can pass the other. At their meeting place, the exact middle of the string, the forces are equal and opposite, so that a *node* or point of greatly diminished amplitude of motion is formed. The two pulses therefore have no option but to continue vibrating independently, thus dividing the string into two independently vibrating halves, each of double the original speed. See the illustration figure 7.

Meanwhile a second impulse from the hand begins to travel along the cord and upon its meeting the already segmented halves the result is a further reflection and subdivision. This again contimnes still further at the next impulse, so that finally, if the impulses can be kept up long enough, the result will be the division of the cord into four, five, six, and up to perhaps ten of these "ventral segments," separated by nodes.

Harmonic Motion. This being the mode of vibration of slow moving cords, we can see how the rapidly moving piano strings are instantly thrown into the state of complex vibration described above; for we must remember that not only is the vibration very rapid, ranging from 27 to more than 4100 vibrations per second, but also that there is no limit to the possible number of subdivisions. Moreover, the piano string is very stiff and being fixed at both ends and excited by a stiff blow, its motion is not only rapid but powerful, so that the reflections are unusually strong and numerous. Hence the wave of motion of the piano string is remarkably complex.

Resultant Motion. The entire complex motion



of the piano string is of course the result of the operation of many forces, moving from different directions, upon a single resistance; so that the result of the interference of the forces with each other is that their net efficiency works out in some direction which is a resultant of all the directions. Thus, the piano string, if it be examined under motion by any optical method, is seen to vibrate in a wave motion which is the resultant of all the partial motions. The general appearance of such a wave is as shown in the illustration, figure 8, which gives (theoretically) the resultant of a wave motion including subdivision into six segments.[1] The piano usually has the first eight and often the ninth, in the lower and middle registers, and still higher partials in the high treble, but the latter can hardly be isolated without special apparatus; and then not easily. Of course, as we shall see later, there are certain causes which affect the form of the wave in the piano string, in practical

[1] This illustration is after the original by Prof. A. M. Mayer, of Stevens Institute, one of the most eminent of American aconsticians. Professor Mayer's drawings of harmonic curves and resultants were first published in the *Philosophical Magazine* for 1875. In order to show clearly the six separate wave motions, their respective amplitudes have been made proportional to wave length. This is of course a scientific fiction, but the effect upon the resultant curve is not markedly distorting.

conditions, and so modify the series of partials.

Fourier's Theorem. One of the greatest of French mathematicians, Fourier, investigating another subject altogether, discovered the law of this harmonic motion of a string when he showed that every complex vibratory motion can be reduced to a series of simple pendular motions, of which the terms are as follows:

1, ½, ⅓, ¼, ⅕, ⅙, ⅐, ⅛, ⅑, ⅒, *etc. ad infinitum.*

In other words, the very subdivision of the piano string into segments is here shown mathematically to be the necessary basis of all compound motion in vibrational form. Thus mathematics, from another angle, amply confirms the ideas above set forth.[1]

Partial Tones. The string, then, vibrates in its whole length, its ½, ⅓, ¼, ⅕, ⅙, ⅐, ⅛, and smaller segments indefinitely. The whole length vibration produces the fundamental tone of the string. The ½ gives twice as many vibrations, or the octave above. The ⅓ gives the twelfth, and the ¼ gives the double octave. Thus, the piano string C-64, when sounded, actually involves not only the fundamental tone but all the following:

[1] J. B. Fourier, 1768–1830, author of "Analysis of Determinate Equations."

Influence of Partials. It should be remembered that, although all the odd- and most of the even-numbered partials above the 10th are dissonant and this dissonance progressively increases—if one may use the term—the number of partials that may occur above the 10th in a piano string is quite large. This being the case, it will be understood that although these partials are relatively feeble, and their sounds do not affect the general sensation of pitch, they do have another effect; and this is felt in what is called the "quality" or "color" of the sound. In fact, as we shall soon see, the harshness or mellowness, thinness or fullness, of a sound, as evoked from the piano, not to mention the greater characteristic differences which distinguish the tone of one instrument from that of another, are all to be attributed to the manner in which the various partials are mixed with the fundamental.

Series of Partials. But why should there be from one piano string a mixture of partial tones different from that which persists in another? For that matter, since the tendency of other sonorous bodies, like pipes for instance, is to divide up naturally into ventral segments, like strings, why should not all tone quality be alike? Obviously the difference must arise because one wave form varies from another; or in other words because one string or pipe or rod produces one specific mixture of partials and another a different mixture. Why this should be so in the case of the piano string, which is our present concern, I shall now comprehensively explain, and the following discussion will be of great assistance in promoting an understanding of some most important problems.

Point of Contact. The piano string is excited by a more or less violent blow from a felt-covered hammer. The impulse thus given to the string is relatively powerful, and its effect upon the highly tensioned filament of steel is such as to induce instant reflection of the sound-impulse and subdivision of the string into many ventral segments. But the exact individual segments into which the subdivision takes place are determined by one special condition; namely, by the position of the hammer's point of contact. As will be remembered, the segments of the string are separated from each other by points of apparent rest called nodes. Of course, these nodes are not actually at rest, but the amplitude of their motion is greatly restricted by reason of the opposed forces pulling from each side upon them. If now the exciting blow is struck exactly on one of the nodes, the vibration of the shorter of the two segments into which that node divides the string, and equally the vibrations of all multiples thereof, are blotted out. Thus, if we wish to eliminate the 7th partial, we must strike on the 7th node, that is to say at exactly 1/7 of the string's speaking length. It is obvious that since the first six partials are simply components of the common chord of the fundamental or 1st partial, and the 8th is triple octave thereto, the elimination of the 7th will produce a perfectly harmonious flow of partials and in consequence a full round mellow tone. Experience confirms this deduction, although the exigencies of piano building usually compel a striking distance, as it is called, positioned at 1/8 or even higher for the greater number of the strings, and running progressively higher in the upper treble till it sometimes reaches 1/24 at the extreme C_7. The influence of contact point position is thus clearly shown, for if any of the very high strings be purposely struck at lower points than the hammers are fixed to strike them, it will be found that their tone is less bright, more mellow and even feebler. The last quality is due to the fact that the prime or 1st partial of these short stiff strings is not sufficiently powerful of itself and needs the backing, as one may say, of many partials to give it consistency and "ring." It might be remembered incidentally that in the two highest octaves of the piano the progressively higher contact points of the hammers on the strings introduce series of partials running from the first ten to the first twenty. But the longer and more naturally powerful strings are struck at about ⅛ of their distance and would often be better off if struck at ⅐.

Material. The properties of the material from which the string is made are also of importance in considering the precise nature of the mixture of partials which any given example may show. The stiffer a string is, other things being equal, the more rapid and complex will be the reflections of wave-motion and the consequent formation of ventral segments. By stiffness I do not mean thickness; for of course the thicker the string the less intense will be the wave-reflections and the fewer the high partials produced. But the piano is peculiar in that the tension of its strings does not vary largely from one end to the other, whilst the thickness does indeed differ very largely in proportion, since even in the understrung part of the scale the difference betwen the extreme treble and the first above the overstrung will usually be something like the difference between 5 and 8. So it follows that the upper treble strings are very much stiffer than those in the lower regions, in proportion to their length. Of course, the length factor enters into the complex here too, for the higher strings are shorter, and so again stiffer, for any given stretching force.

Wire density. In the circumstances it would seem, after one has tested various pianos of various grades, that the idea of intensely hard wire is most distinctly a wrong idea; at least if we are trying to get round full tone and not hard glitter. The very hard wire is no longer so generally demanded; and piano makers are begining to require a string of softer steel which shall tend to produce, under the lowered tension conditions thus made necessary, vibrational mixtures involving fewer ventral segments, the upper of which with their consequent partials shall be less prominent.

String Tension. A softer wire cannot withstand excessive tensions. But we can easily see that high tension means stiffness, and one only has to listen critically to the tone of most pianos to realize that their strings do not err on the side of resiliency. They are usually too stiff as it is, and although the craze for clang and noise seems to be dying out—for which we should be thankful—still, there is much to be done yet. The piano of the future, let us hope, will be a low tension piano, equipped with softer wire and with a hammer shaped and positioned to kill the 7th harmonic and all its multiples; a piano which will have few partials in its tone above the seventh and which in consequence will evoke sounds, full, mellow and sustained in quality.[1]

Voicing. In Chapter IX of this book, I make use of the material here set forth in order to show the practical application of Acoustical science to the work of tone-regulating or voicing pianos by manipulation of the hammer felt.

Simultaneous String Vibrations. We shall now have to face the last and in some ways the most fascinating of all the subjects which we shall confront in the course of our examination into the vibrations of the piano string. So far we have

[1] Other piano string characteristics: For some special cases exhibited by piano strings under practical conditions, the reader may consult Chapter VII. Piano bass strings: The special cases exhibited by the covered strings for the bass tones, are discussed in Chapter VII.

confined our thought to individual strings sounding alone. We now have to consider the very beautiful and important phenomena arising from the sounding of two tones simultaneously. The inquiry is of the utmost importance in the higher analysis of piano tuning.

Beats. The piano serves us again to good purpose in examining the behavior of simultaneously sounded tones. Let us damp off one string in a triple unison on the piano. (All strings of the modern piano above the overstrung section are strung with three strings to the note.) This will leave two strings vibrating. If the piano has not been tuned very recently, it is almost certain that when we listen carefully to the sounding of these two strings we shall hear a sort of sound that can only be described as discontinuous and "wavy." In order to make sure, suppose we choose the strings corresponding to $C_3 = 258.65$ (middle C at international pitch). Let us damp one string of the triple and then slightly turn the pin of one of the others so as definitely to put it out of tune with its fellow. A very slight turn, just enough to feel the string give, will be sufficient. Now, take a tuning fork sounding exactly the same international pitch $C_3 = 258.65$: Sound

back for a few moments to some earlier considerations. A sound-wave is an oscillation to *and* fro. When a tuning fork prong vibrates, the first half of the vibration is when the prong moves away from its rest position and pushes the air in front of it against the surrounding air. This part of the vibration has the effect of compressing the air on that side, whilst on the other side the air moves forward to fill up the vacuum left by the moving away of the prong and thus is rarefied or thinned. Consider a vibrating pendulum (Fig. 10), and think of it as if it were a slow moving tuning fork. As the pendulum moves in one direction it condenses or compresses the air in front of it, and then as it moves back that same air is again rarefied or thinned out to its original density; for air is elastic and rebounds. Thus each complete vibration of tuning-fork, string, or pendulum, no matter how slow or rapid, produces a condensation followed by a rarefaction of the surrounding air.

Wave-length. The space or distance between one condensation and the next, or between one

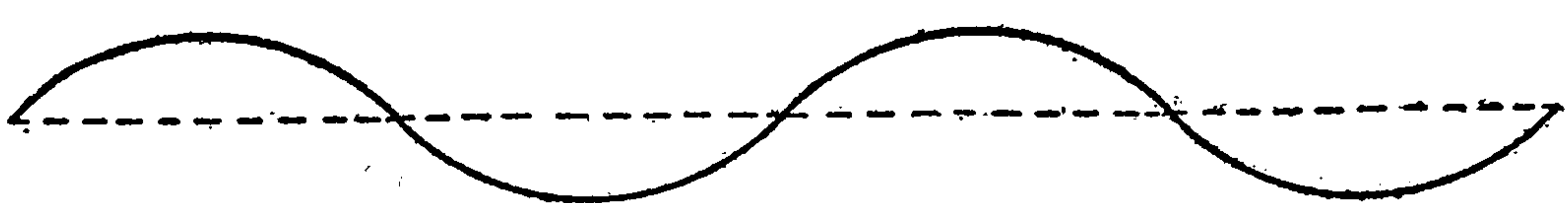


FIGURE 11.

rarefaction and the next, is called the wave-length. The more of these pulses there are in a second or other unit of time, the shorter the length of each. Sound travels at the rate of 1100 feet per second, roughly speaking—the wave-length of a tone of 100 vibrations per second therefore is $^{1100}/_{100}$ or 11 feet. Figure 11 illustrates this point.

Phase. Thus we see that a sound-wave propagated through the air consists of a series of these oscillations of rarefaction and condensation.

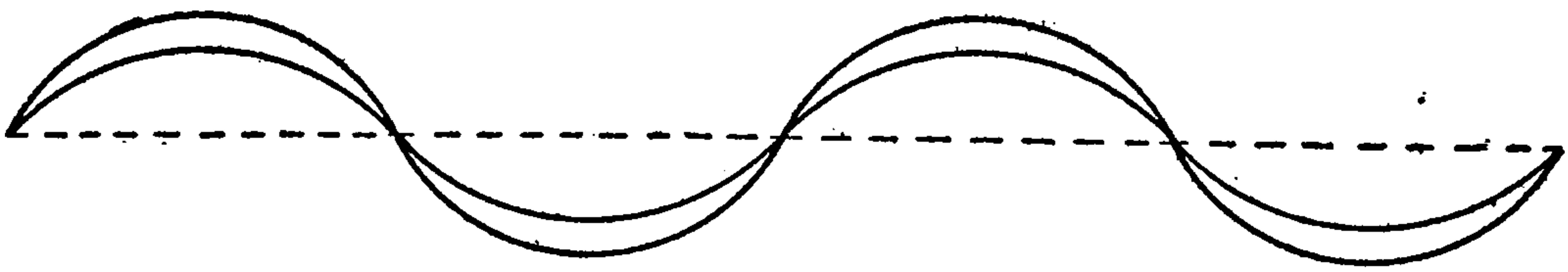


FIGURE 12.

Now suppose that you start two such wave systems simultaneously from two strings perfectly in tune. Start them exactly at the same time so that the condensations begin together. A good example is the striking of two strings at once on the piano. The two run exactly together, condensation with condensation and rarefaction with rarefaction, as is shown by Figure 12, and are said to be in the *same phase.*

Difference of Phase. Now suppose we can arrange to start one string vibrating just half a complete vibration behind the other. Then condensation of No. 2 begins with the first rarefac-

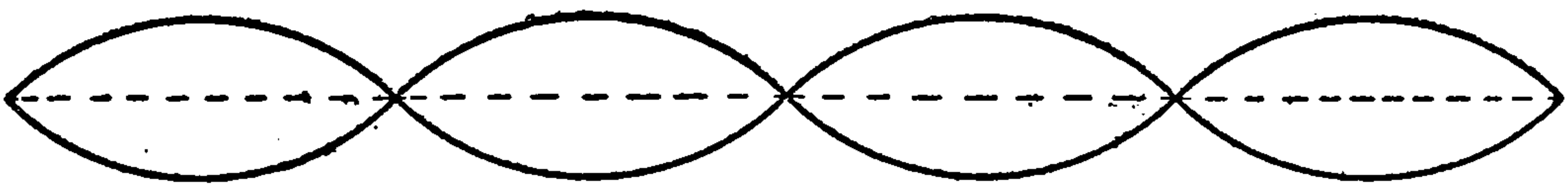


FIGURE 13.

tion of No. 1 and we have the state of affairs pictured in Figure 13. Such a condition is called *difference of phase.*

Difference of one vibration. Suppose two piano strings, one of which gives just one vibration less per second than the other. Now, when these two strings are sounded simultaneously, it follows that at the end of a whole second one will be exactly one vibration behind the other. Likewise at the end of half a second one will be half a vibration behind the other; or in other words at the end of half a second, or right in the middle of one secoud's complete series of vibrations, the two will be in different phases, while at the end of a whole second they will have regained identity of phase; will be in the same phase together again. Suppose now we lay out on paper two wave systems, whose frequencies shall be in the ratio 8 : 9, for the

FIGURE 14.

sake of simplicity. Let us also show, by a third wave-curve, the result of the simultaneous activities of the two waves. In order to avoid a complex drawing I show just eight vibrations of the one and nine of the other. These will consequently begin and end together.

Resonance and Interference. Now as soon as we examine these superimposed curves, we see that at the second complete vibration they are distinctly out of step with each other and by the time one has made four complete vibrations they are in definitely opposite phase. From this point onwards the difference subsides until at the eighth vibration of the one and the ninth of the other, the phase is again the same for both.

Now, it will at once be seen that when the two waves start, two condensations come together and so we have one condensation on top of the other, which of course means an increase in amplitude of the combined sound. Hence at the beginning of the waves the sound of the combined tones will be increased over the sound of either of them alone. We have a condition of *resonance,* as it is called.

On the other hand, when the middle of the curve has been reached we see that the condensation of one meets the rarefaction of the other exactly, so that at this point the one wave blots out the other and produces a perfect *interference* as it is called, cancelling the sound altogether.

Hence we have the rise and fall of sound which we heard so clearly in the two piano strings mentioned above.[1] This rise and fall is very distinct and in the present case would occur at each 8-to-9 period; in other words, if the two waves were vibrating at 80 and 90 vibrations per second respectively, there would be heard 10 beats per second between them when sounded together.

Frequency of Beats. Beats therefore arise between sounds nominally in unison but actually slightly out of tune with each other. The number of beats in a given time is equal to the difference between the frequencies of the generating tones.

Coincident Partials. Beats arise only between

[1] See pages 60 and 61.

unisons. When heard in such intervals as the Octave, Fifth, Fourth, Third or others, this is because partial tones which may be common to both are thrown out of tune slightly; and the beats arise between them. For instance, the beats in an octave which is somewhat out of tune arise between the prime of the upper tone and the second of the lower; which are the same. Example: $C_1 = 64$ and $C_2 = 128$. Prime of the higher is 128. Second of the lower is 128.[1] These are therefore coincident, and if the strings which produce the primes are not in accord, the coincident partials will generate beats as above. The same is true in the interval of a perfect Fifth where the coincident partials are the 2nd of the higher and the 3rd of the lower. Please observe that the coincident partials always bear the same numbers as express the ratio of the fundamentals. Thus octave ratio $= 1:2$ and coincident partials are 2 and 1. Fifth ratio $= 2:3$ and coincident partials are 3 and 2. Fourth ratio $= 3:4$, and coincident partials are 4 and 3; and so on for all other intervals. For instance: Suppose one tone $= 200$ and another $= 301$. The interval is a Fifth, slightly out of tune, as the higher should be

[1] See *supra*, p. 53.

counting beats, whether they call the process by this name or another. The point I am making here is that this process is the proper and natural process and that it is capable of being established mathematically, as has been done by Mr. J. C. Miller of Lincoln, Neb.; whose researches I am happy to be able to make use of in this book, as will be seen later.

We have now discussed to such an extent as is necessary for our present purposes the behavior of piano strings in vibration; and have discovered that this discussion, if properly understood, is found to give us all needed assistance in both tuning and voicing, provided we can calculate the necessary frequencies of the tones required on the piano. We already know [1] that the piano does not permit pure tuning of the diatonic scale but that a system of compromise must be adopted to accommodate the inequalities of the diatonic scale to the unyielding 12 keys of the piano's octave. The system of Temperament used for this purpose, called the Equal Temperament, is now so firmly ingrained in practice that it is in fact the real basis of all modern music; rather than the diatonic scale, which indeed is now little more

[1] *Supra,* Chap. I.

than an artificial abstraction. Of this, however, I shall speak in the next chapter.

If the present chapter has seemed at all involved this is only because I have had to treat an involved subject in simple language and small space. Still, all I have said here has been necessary and forms part of the argument which I am developing as to a system of piano tuning and tone-regulating; based on science and not on guesses or rule-of-thumb—and a good deal easier than if it were so based.

For, indeed, among all the ridiculous superstitions of the human mind, none is either commoner or more absurd than that which covers with contempt the efforts of pioneers to formulate and apply scientific method. In truth, to do things scientifically is always to do them in the easiest as well as the best, way; and your "practical man," untainted with one touch of theory, wastes time and energy in equal proportion.

Chapter III.

TEMPERAMENT.

We have reached the central position in the science of tuning. What has gone before has been enough to show that one cannot obtain a series of pure diatonic scales, in the quantity required for the performance of music, with a key-board comprising only twelve keys to the octave. The particular method adopted in Chapter I for the purpose of showing the truth of this assertion might of course be matched by a dozen others; without altering the facts in the least. For example, I might have pointed out that an ascending series of perfectly tuned perfect Fifths, although nominally equal to seven Octaves, yet actually exceeds them. I might have shown that three major Thirds should be equal to an Octave, if tuned pure one above the other; but that in fact they fall considerably short thereof. There are many other possible illustrations; but I have already shown, in the simplest manner, that some form of compromise is needed if pianos are to be tuned so as to make the performance of music in all tonalities tolerable despite the defective and inadequate 12-to-the-octave key-board.

The word Temperament is generically used to indicate any one of the many such systems that have been, at one time or another, proposed and used. It must be remembered that the present type of key-board dates certainly from the 14th century and has scarcely undergone any change in details—positively none in essentials—during all that time.[1] This is an amazing commentary on the slowness of the human mind and its hatred of change. It is a fact that the width of an octave, even, has remained the same for certainly three hundred years. And the same slowness of development is true in other details.[2]

Influence of the key-board. The truth implied

[1] A terra-cotta model showing a rudimentary form of key-board used with an Hydraulikon or water-organ, has been found in the ruins of Carthage, and is assigned to the second century A. D. Cf. A. J. Hipkins' "Introduction to the Key-board Instrument Collection," Metropolitan Museum of Art, New York.

[2] The great organ at Halberstadt, Germany, built in 1361 by the priest Nicholas Faber, had a complete chromatic key-board, but with very wide keys. However, sixteenth century clavichords are preserved showing key-boards essentially identical with that of the modern piano in width and even in mounting.

in Chapter I may now be realized completely: that the key-board has always exercised a distinctly enslaving influence upon the development of music. If we were not chained to the 12-note key-board by the tradition of music teaching and of piano making, we should soon have a substitute, as easily taught to the hand, whereby at least the grosser imperfections of any temperament system might be avoided. But to hope this is to hope too much.

Meaning of Temperament. Actually, the word Temperament means "tuning"; nothing else. Its derivations from the Italian and thence from the Latin, show this clearly. To "temper" sounds is to tune them. And this fact indicates that the necessity for a compromise from purity was recognized very early and that just intonation has never been even near accomplishment in ordinary practice. In fact the system of Temperament now in use is probably the best that has yet been contrived, although it has had one rival whose claims are not to be despised.

Equal Temperament. The twelve keys within the octave must, of course, represent amongst themselves the various degrees or steps of relationship existing within that interval. Seeing that we cannot gain purity of ratio with only twelve keys, it follows that we must divide up the octave in some way that will admit, as adequately as may be, of performing required music in a tolerable manner. Equal Temperament is the name given to a system of dividing up the octave into twelve equal parts. This being the case and the pitch proportion of the octave interval being 1:2, it follows that the proportion from semitone to semitone in equal temperament is $1:\sqrt[12]{2}$ or 1:1.0594631, correct to seven places of decimals. This ratio is the ratio of the equal semitone, upon which the system is based.

The Equal Tempered Scale. This being so, we have only to select some standard of pitch for some one tone and calculate up and down therefrom by the simple process of multiplying or dividing, semitone by semitone, by the factor 1.0594631.

The octave of course remains the one interval which retains its purity. This is so, because we must have a system of some sort and the octave provides a foundation therefor. Hence the octave remains pure, and so if we once calculate the equal tempered pitch of the 12 semitones in one octave we can obtain that of any one of the tones situated in any other octave by multiplying by 2 for each octave of distance upwards or dividing by 2 for each octave of distance downwards.

Thus we may say that Equal Temperament is a system in which the octave interval is tuned pure and all other intervals are tuned in such a way as to produce a tone-series of 12 equal parts within each octave.

International Pitch. The nominal standard now recognized for the basis of pitch in the United States is $A_3 = 435$. This is the same as the French Normal Diapason, from which indeed it is taken. Assuming this as our standard, we have the following frequencies for the A throughout the compass of the piano, beginning at the lowest:

$$A_{-1} = 27.1875$$
$$A = 54.375$$
$$A_1 = 108.75$$
$$A_2 = 217.5$$
$$A_3 = 435$$
$$A_4 = 870$$
$$A_5 = 1740$$
$$A_6 = 3480$$

The piano's scale in equal temperament. With the above figures as our standard of measurement, and multiplying for each semitone upwards by the

TABLE I. SHOWING FREQUENCES (V. P. S.) OF ALL TONES ON THE PIANO, BASED ON INTERNATIONAL PITCH AND CORRECT TO TWO PLACES OF DECIMALS

Name	Sub Octave	C Octave	C_1 Octave	C_2 Octave	C_3 Octave	C_4 Octave	C_5 Octave	C_6 Octave	C_7 Octave
A	27.18	....	....	......	......	......	......	......	....
A♯—B♭	28.8	....	....	......	......	......	......	......	....
B —C♭	30.5	....	....	......	......	......	......	......	....
C —B♯	....	32.08	64.16	129.32	258.65	517.3	1034.6	2069.2	....
C♯—D♭	....	34.25	68.50	137.0	274.0	548.0	1096.0	2192.0	....
D	....	36.27	72.55	145.1	290.2	580.5	1161.0	2322.0	....
D♯—E♭	....	38.42	76.85	153.7	307.5	615.1	1230.2	2460.4	....
E —F♭	....	40.77	81.45	162.9	325.9	651.8	1303.6	2607.2	....
F —E♯	....	43.15	86.3	172.6	345.3	690.6	1381.2	2762.4	....
F♯—G♭	....	45.7	91.4	182.8	365.7	731.5	1463.0	2926.0	....
[illegible]	....	48.42	96.85	193.7	387.5	775.0	1550.0	3100.0	....
G♯—A♭	....	51.3	102.6	205.2	410.5	821.0	1642.0	3284.0	....
A	....	54.37	108.75	217.50	435.00	870.00	1740.00	3480.00	....
A♯—B♭	....	57.6	115.2	230.4	460.8	921.6	1843.2	3686.4	....
B —C♭	....	61.0	122.05	244.1	488.2	976.4	1952.8	3905.6	....
C	....	....	....	......	......	......	......	......	4138.4

worked out on the equal semitone system as explained.

Comparison of Intonations. Before undertaking to show how tuning in Equal Temperament may most easily be performed, I shall give here a comparison, for the student's benefit, of three pure major diatonic scales built on two of the tempered tone degrees taken from Table I.[1] The first scale is the tempered scale, the second is a pure diatonic

TABLE II. COMPARATIVE FREQUENCES OF TEMPERED SCALE AND THREE DIATONIC MAJOR SCALES TAKEN ON 1ST, 2ND, AND 3RD CHROMATIC TEMPERED DEGREES OF TEMPERED SCALE

Equal Tempered C Scale (Chromatic)	Pure Diatonic C Scale (Major)	Pure Diatonic D Scale (Major)	Pure Diatonic D♭ Scale (Major)
C_2 ....258.65	C_2 ....258.65	....	....
C♯—D♭ ..274.00	....	D_2 ....290.2	D♭ 274.00
D 290.2	D 290.98	....	....
D♯—E♭ ..307.5	....	E 326.47	E♭ 308.25
E 325.9	E 323.3	....	....
F 345.3	F 344.8	F♯ 362.75	F 342.5
F♯—G♭ ..365.7	....	G 386.93	G♭ 365.33
G 387.5	G 387.97	....	....
G♯—A♭ ..410.5	....	A 435.3	A♭ 411.00
A ....435.	A 431.08	....	....
A♯—B♭ ..460.8	....	B 483.66	B♭ 456.66
B 488.2	B 484.97	....	....
C_3 ....517.3	C_3 .....517.3	....	C 513.75
C♯—D♭ ..548.	....	$C\sharp_3$ ...544.12	D♭ 548.00
D ....580.	....	D_3 ....580.	....

1 The minor scale has not been considered because its difference from the major is merely in the detail of intervals. The arguments already made apply with equal force to the minor scale. See *supra.* Chap. I.

major scale built on the same $C_3 = 258.65$, the second in a pure major diatonic scale built on the tempered major second to C (D), and the third a pure diatonic major built on the tempered D flat. The pure diatonic scales are worked out from each on the basis of the ratios of the diatonic scale major (*supra* Chapter I); and the object of the comparison is simply to show what effect the Equal Temperament has on purity of intonation.

Advantages of Equal Temperament. These tables show clearly some of the peculiar defects of the Equal Temperament; but they show also some of its peculiar advantages. For it will be seen that at the cost of some perceptible dissonances in certain intervals—dissonances which we shall shortly calculate definitely—we gain the ability to perform music in all tonalities, by aid of the traditional 12-note key-board.

Disadvantages of Equal Temperament. At the same time we must not lose sight of the fact that in reality the Equal Temperament is a compromise, and a loose compromise, with fact. If it were not for the organ and piano, the imperfections of Equal Temperament would be more easily perceived; but the dynamic powers and immense harmonic resources of these two instruments have endeared them to musicians and have concealed the roughness of their intonation. No one who has read the previous chapter and understands how to listen for beats, however, can long endure the intonation of the organ on such intervals as minor thirds. The sustained tones of that instrument bring out beats very clearly and produce a generally distressing effect for delicate ears. Of course, the truth is that most of us are so used to tempered intonation that we recognize nothing else and know of no other possibility. Yet the fact remains that whoever has heard one of the few experimental key-board instruments that have been constructed to play in pure intonation has been entranced with the sweetness of music thus played. It is far more beautiful than tempered intonation and in fact seems to impart to the music of these instruments a new sweetness and concord.

So long, of course, as the manufacture of pianos and organs is stressed rather on its industrial than on its artistic side we shall probably have to remain content with Equal Temperament. But it might as well be observed that if the piano and organ were out of the way, music throughout the world would be on some basis of tuning other than Equal Temperament within ten years.[1]

Meanwhile we must be content to tune in Equal Temperament as well as we can, knowing that when such work is well done it is very satisfactory and serves well the requirements of modern music and modern musicians.

Meantone Temperament. Before going on to consider the method of tuning in Equal Temperament, however, I should like to mention the immediate predecessor of the Equal Temperament; the famous Meantone Temperament, which flourished from the 16th to the early part of the 19th century and may be occasionally found to-day on organs in obscure European villages. This system consists in tuning a circle of fifths equally flat, in such a way as to leave all the thirds major nearly pure. In order, however, to be used for all required keys, it is necessary to have extra key-levers, for the flats and sharps of adjacent tones are not identical. For perfect performance in all tonalities, not less than 27 tones to the octave are

[1] The reader who doubts this might consult Ellis (App. 20 to Helmholtz), Helmholtz, chapter 16, Perronet Thompson, "Theory and Practice of Just Intonation," and Zahm, "Sound and Music." My own book, "Theory and Practice of Pianoforte Building," contains a close analysis of the requirements of Just Intonation.

required, but the greater number of tonalities can be used with 16 keys to the octave; the additional tones being for D flat, E flat, A flat and B flat. The ordinary 12-tone key-board would give, of course, starting from C, only the circle of Fifths, which when transposed to the same octave result in the following scale:

C, C♯, D, D♯, E, F, F♯, G, G♯, A, A♯, B.

Unfortunately, in this temperament, C♯ will not do for D flat, D♯ for E flat, G♯ for A flat or A♯ for B flat. These tones of course have to be incorporated somehow and in some 18th century organs were built into the manual by dividing up some of the black keys, which were cut across the middle with the back half slightly raised above the front. The meantone system gives a "sweet" and harmonious effect for nearly all keys, with 16 tones to the octave, although of course this number still lacks 11 tones to make it quite adequate. However, even with 12 tones to the octave, an experiment in meantone temperament can be tried, and will sound very attractive so long as one keeps within the range of keys allowable. To make the best of the key-board we have, the following method may be tried. Start with C and tune the major third C—E perfect. Then tune the fifths from C round to E by Fifths and Octaves, equally flat, testing until the right degree of flatness is obtained. All other notes can be had by tuning pure major Thirds and pure Octaves. By this system it is possible to play in the keys of B flat, F, C, D and A major, and G, D, and A minor. The reason, of course, is as stated below. This is a very useful experiment and if tried out carefully will enable the student to play old music in the tuning for which it was intended; an experience sometimes most illuminating and delightful.[1]

The "Beat" System. I have mentioned these things because I am anxious to have the student understand that the Equal Temperament is not the only possible system of tuning. But to get now definitely to the method of tuning in Equal Temperament, which is the system which the tuner to-day uses universally, let us see what is the nature of our problem.

The Table of frequencies (Table I) suggests the method we shall use. We know [2] that beats afford

[1] The student might consult the extremely useful and interesting article, "Temperament," by James Lecky, in Grove's "Dictionary of Music and Musicians."

[2] *Supra*, Chapter II.

done by means of major and minor Thirds and major and minor Sixths, whose rates of beating in equal temperament the tuner must therefore know.

Beats in Equal Tempered Intervals. The following Table (Table III) gives the number of beats per second in the ascending minor Thirds, major Thirds, Fourths, Fifths, minor Sixths and major Sixths from each degree of the equal tempered scale between C_2 and C_4 inclusive. The rates are, for purposes of convenience, made correct only within .5 vibrations per second. In other words, where an accurate calculation would show any beat-rate as some whole number plus a decimal greater than .5, the rate has been made the next whole number. For instance, 19.73 is counted as 20; while the same course has been adopted for rates where the decimal correctly is less than .5. For instance, 9.31 is made to read 9.5. On this plan the error may be less than .1 or more than .4 vibrations per second. Inasmuch, however, as the tuner will find his powers extended to the utmost in estimating the beat-rates of Fourths and Fifths at the figures given, and with this relatively large error, it has been thought better to adopt this course.

For suggestions as to counting beats and other

TABLE III. APPROXIMATE NUMBER OF BEATS PER SECOND WITH ASCENDING INTERVALS FROM C_2 TO C_4 IN EQUAL TEMPERAMENT

Note	Frequency	Minor Third	Major Third	Perfect Fourth	Perfect Fifth	Minor Sixth	Major Sixth
Pitch Ratio		5:6	4:5	3:4	2:3	5:8	3:5
Coinciding Partials		6:5	5:4	4:3	3:2	8:5	5:3
C_2	129.3	7.0	5.1	.60	.45	8.5	6.0
C♯—D♭	137.0	7.5	5.5	.60	.50	9.0	6.5
D	145.1	8.	6.	.65	.50	9.5	7.0
D♯—E♭	153.7	8.5	6.1	.70	.55	10.0	7.0
E	162.9	9.	6.5	.75	.55	10.5	7.5
F	172.6	9.5	7.	.80	.60	11.0	8.0
F♯—G♭	182.8	10.	7.5	.85	.65	11.5	8.5
G	193.7	10.5	8.	.90	.65	12.5	9.0
G♯—A♭	205.2	11.	8.5	.95	.70	13.0	9.5
A	217.5	12.	9.	1.00	.75	14.0	10.0
A♯—B♭	230.4	12.5	9.5	1.00	.80	14.5	10.5
B	244.1	13.	10.	1.10	.85	15.5	11.0
C_3	258.6	14.	10.5	1.20	.90	16.5	12.0
C♯—D♭	274.0	15.	11.	1.25	.95	17.5	12.5
D	290.2	16.5	11.5	1.30	1.00	18.5	13.0
D♯—E♭	307.5	17.5	12.5	1.40	1.10	19.5	14.0
E	325.9	18.	13.	1.50	1.20	20.5	...
F	345.3	19.	14.	1.60	1.20	...	...
F♯—G♭	365.7	21.	14.5	1.70	...	...	...
G	387.5	21.	15.	1.80	...	...	...
G♯—A♭	410.5	22.	16.5	...	...	...	...
A	435.0	23.5	...	...	...	...	...
A♯—B♭	460.8	...	...	...	...	...	...
B	488.2	...	...	...	...	...	...
C_4	517.3	...	...	...	...	...	...

practical matters of the same sort the following chapters should be consulted.[1]

Use of the Table. I do not propose that the tuner shall try to count accurately the beats per second enumerated above; at least immediately. But the special use of the Table is to provide a model which will indicate closely enough the exact amount of impurity in each interval as required for equal temperament. This impurity is measured by the beat-rate instead of by first showing what the ratios of impurity should be and then proposing a rough approximation thereto to be measured by tuning "about so flat" or "about so sharp." By giving definite beat-rates I make it possible, as the next chapter will show, to tune with unusual accuracy after a reasonable amount of practice.

The immediate point is that the tuner should

[1] The present table is founded on the comprehensive and accurate work of J. C. Miller of Lincoln, Neb., U. S. A., an eminent exponent of the noble art of tuning and a worker in science whose unselfish labors for the benefit of his fellows can never be too much admired. Calculated correct to six places of decimals and with some supplementary matter, the Miller tables were published in *The Tuner's Magazine* (Cincinnati), for December, 1914. A less elaborate edition was published correct to two places of decimals in the *Music Trade Review* (New York) during 1911, and in the London *Music Trades Review* (London), 1914. Those who desire to obtain the complete figures may therefore have them by consulting the publications mentioned.

Although we tune by Fourths and Fifths preferably, it is necessary to understand also the characteristics of the other intervals. Thus:

Three ascending major Thirds nominally coincide with an Octave but actually are short in the ratio 125:128. Hence the major Thirds must be widened in equal temperament, the amount thereof in each case being determined as in Table III.

Four ascending minor Thirds nominally coincide with one Octave but actually exceed it in the ratio 1296:1250. Therefore they must be narrowed in each case, the amount thereof being determined for the tuner by counting the beats as set forth in Table III.

In the same way we find that in Equal Temperament the major Sixths are all wide and the minor Sixths narrow.

Increase in beat-rate. In the nature of the case, the beats taking their origin from coincident partials, and the ratio of pitch from octave to octave being 1:2, it follows that the number of beats in any interval doubles at each octave ascending and halves at each octave descending. By suitable multiplication and division therefore, the beat-rate in any interval in any octave of the piano may be obtained from Table III. It is worth while pausing here to note that the higher octaves comprise intervals in which the beats are very rapid and conversely the lower octaves have very slow beating intervals. Thus the ascending Fifth C—F beats as follows, from the lowest C upwards:

	v. p. s.	
C ....F	.1125	or a little more than 1 in 10 seconds.
C_1....F_1	.225	or nearly 5 times in 20 seconds.
C_2....F_2	.45	or nearly 5 times in 10 seconds.
C_3....F_3	.90	or 9 times in 10 seconds.
C_4....F_4	1.80	or nearly 2 per second (18 times in 10 seconds).
C_5....F_5	3.60	or nearly 4 times per second (36 in 10 seconds).
C_6....F_6	7.20	or about 7 times per second (72 in 10 seconds).

The Fourths and Fifths Circle. My preferred method of tuning is by a circle of Fourths and Fifths. By the method noted on pp. 108–109, Fourths and Fifths are alternated in such a way that after the first descending Fifth has been tuned, *every note to be tuned is flatted, whether it belong to a Fourth or Fifth.* This is made possible by taking all the Fourths descending and all the Fifths ascending, whereby Fourths can be expanded and Fifths contracted in a continuous process of flatting each note in turn; as will at once be seen by glancing at the table mentioned above.[1]

Practical suggestions for tuning this circle according to the beat-rate system will be found in

[1] See pp. 108–109.

the next chapter. The tones are taken in the octave F_2—F_3, around middle C, and the remainder are tuned by octaves up and down. The circle is known among tuners as "the bearings."

A note on the Scientific Method. This concludes all that it is necessary to say about the acoustical foundation of the system universally employed throughout the Occident for the tuning of musical instruments. The practical side of the art is treated in the following chapter. I should not wish to conclude the present remarks, however, without pointing out that I have treated the subject fully but not necessarily obscurely. In point of fact one cannot explain the rationale of Equal Temperament without going into considerable detail. If the reader is content to do without the explanations, and to accept Table III together with the following chapter at their face value, he may skip all that I have set forth in previous pages and take my conclusions as stated. But if he chooses any rapid road like this he will find that rapid roads are often slippery, and he will miss the satisfaction which comes from knowing *why* as well as *how*.

The attentive reader will discover nothing difficult in the method adopted here; and the practical

reason. To get something better we need a method which will either (1) allow more strings to the octave or (2) will give us a mechanism capable of making instant changes as required in the pitch of given strings, so that modulation may be as facile as it is now.[1]

Let it be understood however that Just Intonation is an ideal to be striven for; and that tuners should by all means make it their business to acquaint themselves with the beauty and sweetness of pure intervals, if only to remind themselves that these really exist.

The scope of the present volume does not permit me to go into detail as to experimental instruments that have been made to give Just or nearly Just Intonation, but I wish that every reader would take the trouble to consult the admirable discussion of this most interesting subject to be found in Ellis' 20th Appendix to the 3rd English edition of Helmholtz. At the end of this book I have ventured to give a short list of works which the student who is desirous of pursuing his acoustical and musical studies further, may consult to his advantage.

[1] One such system was worked (by Dr. Hagaman of Cincinnati) some years ago, and one may hope that it may yet be heard of in some commercial practicable form.

Chapter IV.

PRACTICAL TUNING IN EQUAL TEMPERAMENT.

After all the discussion that has gone before, we have now to see how we may put our ideas into practice. It is plain from what has been already said that Equal Temperament is a perfectly simple system and one admirably adapted to present ideas and methods in musical composition and the making of musical instruments. Until there comes that change in public taste which demands something finer, we shall have tempered pianos, tempered orchestras and tempered intonation generally; with our ears more and more becoming used to tempered sounds and unused to pure sounds. It is therefore highly important not only that the tuner should be thoroughly capable of doing the very best work in temperament that can be done, but also that he should make it his business to realize every day and every hour that the work he is doing is in reality a compromise with truth;

necessary no doubt, but a compromise just the same; and one which exists solely because instruments, musicians, and the public alike are unready for anything better.

Recognizing Just Sounds. In the circumstances and considering the inherent difficulty of tempering accurately by estimation of ear, I most earnestly advise every student to practice the tuning of pure Fifths, Fourths, and Thirds. Unisons and octaves must be tuned pure anyhow, but most tuners, in common with virtually everybody else, are familiar only with the tempered form of the other intervals and never dream of asking how they sound when purely intoned. But in order to recognize with any sort of accuracy the number of beats per second that a tempered interval is generating, it is absolutely essential that one should be acquainted with the true condition of that interval; familiar with its sound when evoked in purity. Thus I would counsel every reader of this book to form the habit of always tuning all intervals pure and hearing them satisfactorily as such, before attempting to temper them; and also to get into the equally valuable habit of tuning, for his own amusement and satisfaction, series of pure chords on the piano; which of course can be done, so as to

Unison Tuning. The acquirement of a cultivated ear for purity of interval cannot better be begun than by learning to tune unisons correctly. Considering also that tuning of unisons comprises about two-thirds of the work of tuning a piano, since most of the tones are triple, and nearly all the rest double, strung, it will be seen that this important part of the tuner's work deserves the most careful attention. It is fortunate that the unison is the simplest of intervals to comprehend and to appreciate aurally. It is requisite in beginning the study of tuning to ascertain with complete certainty the peculiarities of beats. Two tuning forks tuned in unison and with one then slightly loaded with a minute piece of wax, or other material, afford a simple and easy experiment in beat production.[1] It will be useful to begin by making such an experiment and listening carefully to the beats until the peculiar rise and fall of the sound is so plain that it can never again be mistaken. The opposite experiment, made by removing the load and returning the forks to complete unison, presents the sound of a perfect unison, with complete absence of beats. It is also, by the way, interest-

[1] Cf. Chapter II.

ing as providing an almost perfect form of simple vibration, without partials.

To tune two piano strings in unison is not a very difficult task if it be gone about rightly. In the first place, it is well to listen carefully to the work of a professional tuner, when the opportunity occurs, with the object of noting by ear how he adjusts his unisons. A little practice will enable one to hear instantly the difference between the beating tone of two strings which are out of tune with each other and the pure continuous beatless sensation of tone developed when the unison is perfected. Having once obtained some facility in thus cultivating the hearing, the student may obtain a tuning hammer and attempt to do some practical adjustment of unisons.

Argument concerning the manipulation of the hammer would at this stage be out of place, I feel, for it would tend rather to confuse than to assist the student.[1] Let me then simply say that the tuning hammer is to be placed on a tuning-pin corresponding with one string of a triple unison. Let one string of the triple unison be damped off, leaving two to sound when the piano digital is

[1] But see the next chapter.

struck. If the piano has not been tuned recently the student will undoubtedly hear beats; and if these are not distinct or frequent enough, let the tension on the string be relaxed by turning the pin slightly toward the left or bass end of the piano. Now, let the reverse operation be undertaken, and the hammer turned back towards the operator, thus gradually tightening up the string again. As this is done it will be observed, if the digital is repeatedly struck, that the beats, which at first we may suppose to have been quite frequent, become slower and slower, until if the string be rightly tuned, they disappear altogether, leaving a pure continuous uninterrupted sound.

Practice. In beginning the work of learning to tune pianos, it is advisable to practice for some time in bursts of from fifteen to thirty minutes each, on simple adjustment of unisons. The manipulation of the hammer, of which I speak at length in the next chapter, now, of course, begins to claim attention; but for the present it is enough to say that the pin must be turned without wrenching its outer end and without pulling downwards on it. It is advisable to rest the arm and keep the handle of the tuning hammer nearly vertical.

It will then be advisable to undertake settling

ness, as the Octave is perfected, until a perfect Octave is almost as complete a blend of sound as an unison.

Exact Tests. In certain regions of the Piano it is quite impossible to obtain certainty of Octave tuning merely by estimating the extinction of beats between the two members of the interval. In the low bass particularly, the coarseness of the strings and the almost inevitable impurity of their intonation lead to the generation of all kinds of false beats which confuse the student and are a source of annoyance and inaccuracy even to the expert. The student should of course practice tuning Octaves throughout the entire compass, but he will find that in the low bass he must have some test for accuracy better than afforded by aural comparison of the two members of the interval. Fortunately, other tests are available, and each is capable of giving highly correct results.

The Octave comprises a Fourth and a Fifth in succession. A Fourth above C_2 runs to F_2 and a Fifth from that runs from F_2 to C_3. If now, whilst tuning the octave C_2—C_3 (say) we sound the Fourth C_2—F_2 and then the Fifth F_2—C_3, and find the beats in the Fourth equal in number to the beats in the Fifth, the Octave is tuned accurately.

This is so because all Fourths and Fifths in Equal Temperament are distorted slightly so that the coincident partials are actually a little distorted also. In the present case, the coincident partial is C_4, the 4th partial of C_2, the 3rd of F_2 and the 2nd of C_3.

The first octave test therefore is made by ascertaining the number of beats between the Fourth above the lower sound and comparing these with the beats in the Fifth below the upper sound. If the beats are the same in number, then the octave is perfect. But, if the test is made between lower Fifth and upper Fourth, then the upper Fourth will beat twice as fast as the lower Fifth.

Minor 3rd and major 6th. For the lower regions of the piano especially, but useful everywhere, is the test of the ascending minor Third and descending major Sixth. If we are tuning, for instance, from C_2 to C_3, we try the minor Third C_2—E $flat_2$ and note its beat-rate. Then we try the major Sixth E $flat_2$—C_3 and try its beats. If the beats in the two cases are equal in rate, then the octave is tuned accurately. It will be observed that this is the same idea set forth in the previous paragraph. The E flat is the common tone, and the minor Third and major Sixth are complementary. The coincident partial is the 6th of C_2, the 5th of E flat$_2$ and the 3rd of $C_3=G_4$. But if the Sixth be the lower and the Third the upper, complementary intervals used, the Third will beat twice as fast as the Sixth.

Beat rates in Thirds and Sixths. It is well to note in passing that as shown in the tables in Chapter III (*supra*), the beats in Thirds and Sixths, major and minor, are considerably faster than in Fourths and Fifths; and the student after tuning an octave may profitably examine the complementary Thirds and Sixths within that interval for the purpose of studying their beat rates.

The Tenth test. A Tenth is an Octave plus a major Third. A good octave test is to be found here also by using the major under-Third and Tenth. If tuning C_2 to C_3, test by the major under-Third C_2—A flat$_1$ as compared with the Tenth A flat$_1$—C_3. The coincident partial is the 5th of A flat$_1$, the 4th of C_2 and the 2nd of C_3,$=C_4$. This test is useful throughout the entire compass and especially in the lower registers.

Observe that beat-rates, as shown by Table III (Chapter III), vary as the frequencies of their generators, so that the nearer we approach the lower bass, the slower are all the beat-rates. In

Seconds' Watch. Watches are usually provided with seconds' hands and these usually make four ticks per second. By listening carefully for say ten minutes at a time, the student can soon learn to hear accurately a beat-rate of 4 per second. But the precise tick-rate of one's own watch must be accurately determined.

Pendulum Clock. Pendulum clocks of the large sort often have very slow swinging pendulums. These sometimes produce one complete *to and fro* swing (complete vibration) per second.

Pendulum. Ellis suggests (App. 20 to Helmholtz), that the student may make himself a pendulum from a piece of string and a curtain ring, with provision for shortening or lengthening the string readily. Now, for counting during any length of time, as for instance 5 seconds, which is a useful unit of time in counting beats of the piano, we may arrange the length of the string as shown below:

Length of string from beginning of vibrating portion to middle of ring in inches:	*Complete vibrations (to and fro)* in 10 seconds	in 5 seconds
9⅞	10	5
4⅜	15	7½
27$\frac{3}{16}$	6	3

It is important to note the manner of measuring, as above.

These three beat rates are very important, especially the first and third, in the practical work of tuning.

Other methods may suggest themselves to the student. The perforated rotating disk to be found in every high school physical laboratory can be used also to give series of taps (by holding a card against a circle of the perforations while the disk is rotated), of any required speed.[1]

Of course the point is that the tuner ought not to trust to guess work but should try to *know* when he hears a beat-rate what it really is. He can learn to do this; and learn easily. By watching and counting the swings of a pendulum such as that described above he can soon learn to *feel* the rate of swing; which is an exceedingly valuable accomplishment and one easy to acquire. Certainly, it is impossible without some such training ever really to do distinguished work in the most important and most difficult branch of tun-

[1] The Metronome may likewise be used for the same purpose. The beat-rate required is expressed in terms of beats per minute, then multiplied by 2. The Metronome is set at the resulting figure, and every alternate tick only is counted. Or if a bell is fitted to the Metronome and set to sound on every alternate tick, the result is still better. Thus: 3 beats in 5 seconds = 36 beats per minute. Set Metronome at 72 and make bell sound on alternate ticks. The rate of 3 in 5 seconds will thus be given. The suggestion is due to Mr. August Reisig of New Orleans.

TABLE IV. SCHEME OF LAYING THE BEARINGS IN EQUAL TEMPERAMENT FROM F_2—F_3 BY FOURTHS AND FIFTHS—WITH TESTS

NOTE 1.—5ths must be contracted and 4ths expanded. But by taking all 5ths up and all 4ths down, each succeeding note to be tuned is flatted: thereby simplifying matters. The first F, however, is a 5th *down* and this F (and it alone) is *sharped*.

NOTE 2.—Pitch is International $C_3 = 258.65$. 5ths are contracted, 4ths expanded, minor 3rds contracted, major 3rds expanded, major 6ths expanded, minor 6ths contracted.

Step	Notes	Interval or test chord	Frequencies	Beats per second	Beats in 10 seconds	Beats in 5 seconds
1	C_4—C_3	Octave	517.3 —258.65	0.0	0	0
2	C_3—F_2	perfect fifth	258.65—172.6	.6	6.0	3.0
3	C_3—G_2	perfect fourth	258.65—193.7	.9	9.0	4.5
4	G_2—D_3	perfect fifth	193.7 —290.2	.65	6.5	3.25
5	F_2—D_3	major sixth	172.6 —290.2	8.0	80.0	40.0
6	D_3—A_2	perfect fourth	290.2 —217.5	1.0	10.0	5.0
7	F_2—A_2—C_3	major triad	....	....	....	....
8	F_2—A_2	major third	172.6 —217.5	7.0	70.0	35.0
9	A_2—E_3	perfect fifth	217.5 —325.9	.75	7.5	3.75
10	A_2—C_3—E_3	minor triad	....	....	....	....
11	C_3—E_3	major third	258.65—325.9	10.5	105.0	52.5
12	G_2—E_3	major sixth	193.7 —325.9	9.0	90.0	45.0
13	E_3—B_2	perfect fourth	325.9 —244.1	1.1	11.0	5.5
14	G_2—B_2—D_2	major triad	....	....	....	....
15	G_2—B_2	major third	193.7 —244.1	8.0	80.0	40.0
16	B_2—$F\sharp_2$	perfect fourth	244.1 —182.8	.85	8.5	4.25
17	$F\sharp_2$—A_2—D_3	inverted major triad	....	....	....	....

ing pianos; that which is called "laying the bearings," and which we must now consider.

Laying the Bearings. The scheme already laid out (Chapter III, *supra*), for tuning the central octave in Fourths and Fifths forms the basis of the explanations now to be made: Reproducing this in type and appending the beat-rate as ascertained for each interval from Table III and the frequency as given in Table I, we get Table IV, pages 108–9.

There are two observations to be made immediately. The first is that although the Table shows 36 steps, only 13 notes are actually tuned, and the remaining steps show tests made by intervals and chords generated during the progress of the tuning. These test intervals and chords are of the utmost importance, just as important as any other element of the work, inasmuch as they afford a complete measure of the correctness of the tuner's progress. But the actual tuning is confined to the series of Fourths and Fifths shown.

The second is that to count beats at something very close to these rates is not impossible by any means. I counsel the student to realize that any definite method like this has the inestimable advantage of being founded on fact. What is more to the point, such a method leads to that much closer accuracy which should distinguish masters of the art.

Variations in pitch for practical tuning. The figures given are sufficiently accurate for any pitch between C 258.65 and C 264, which range covers the common variations as found in modern pianos. In strict fact, any rise in pitch above the International C 258.65 involves a progressive rise in beat-rate. But the amount of increase is too small for practical purposes; usually at least.

Importance of Accuracy. Of course I cannot too strongly urge the importance of accuracy, of not being content to do things fairly well or even reasonably well; but of insisting to the utmost upon the possibility of doing ever and ever more accurate, more scientific and more complete, work. Tables III and IV do represent the utmost in accuracy, probably; and the figures given in these Tables can be attained by those who will practice the Art of Tuning with patient devotion. The Artist will attain them. May every reader of this book earnestly strive for that perfection.

Methods of Using Tests. The test Thirds and Sixths, and the test triads are to be used constantly throughout the work. Observe carefully the rise in beat-rate of the ascending Thirds and Sixths.

This rise must be accurately measured. It will be found, of course, that the beat-rate doubles in each octave and the extreme Thirds should show this progress. No better test of the accuracy of the bearings can be found. It is not sufficient to "come out right," by which is meant, to arrive at the last step and find the final octave reasonably clear. It is necessary that every step should be right. This means care, patience, study; which lead to mastery.

Tuning from the Bearings. From the Bearings the tuning proceeds by octaves and unisons according to the methods laid down and explained in the earlier part of this chapter. The student is again warned to look out that his octave tuning does not begin to slide off from accuracy by the accumulation of imperceptible into intolerable errors; and to this end the constant use of the various tests already explained, as well as of double octaves and triads, is recommended.

Obtaining required Temperament in intervals. Lastly, let me say again that the only way to tune intervals so that their beat-rates are reasonably accurate is first to tune them pure and then to make the necessary correction up or down. It is impossible in any other way to acquire true deli-

Chapter V.

MECHANICAL TECHNIQUE OF TUNING.

The art of tuning the piano comprises two distinct and separate elements. That part of our education as tuners which relates to the science of the art has already been discussed in full in the previous chapters. We must now consider what may be called the general mechanical technique of the art, including the special subject of the tools required and their manipulation.

The Raw Material. The raw material with which the tuner works may be described for practical purposes as consisting of the string, the wrest-pin or tuning-pin, the wrest-plank or pin-block, and the tuning hammer. The piano action, the digitals, the wedges for damping strings, and the tuning-fork may alike be considered for the present, as accessory to, rather than as part of, the essential material. Let us consider these in their order.

String Conditions. It is well known, of course, that the pitch of a string—that is to say, its frequency of vibration—varies as the square root of its tension. Hence, if the tension be increased, the frequency is increased likewise; whilst if the tension be relaxed, the pitch is lowered. Now, the tension of a string is increased by tightening it on its pin; that is by turning the pin so as to stretch the string more tightly. The relaxation of tension is achieved in precisely the opposite way; that is, by releasing the string somewhat.

String and Pin. The piano string is wound so that the pin lies, as seen from the front, to its right, on an upright piano and to its left on a grand. But actually the positions are the same, and the difference stated is due to the different position from which we view the strings on an upright and a grand respectively. It would be better to say that the string is always on the treble side of the pin in a horizontal and on the bass side in an upright piano. When the tuner wishes to raise the pitch of a string he turns the pin so as to wind up the string on it. To lower the pitch he turns the pin so as to unwind the string.

The mechanical problem therefore is *to turn the pins in the wrest-plank in such a way as to adjust the pitch of each string to the requirements of the*

Equal Temperament at the standard of pitch agreed on.

The Elements. In following chapters, I give a general description of piano construction and necessarily include remarks on the functions of all the parts herein mentioned. In the present chapter, however, I shall treat these only with relation to the tuner's work.

The String. The piano string varies in length inversely as its pitch and may be from 2 inches to 80 inches long, according to its position in the scale and the size of the piano. Steel music wire is used, varying in diameter from .03″ to .06″. The lower strings are wound with steel or copper overwinding or covering. The tension at which the strings are stretched varies within the limits of 100 and 275 pounds; but it would be fair to name as an average range of tension per string in modern pianos 150 to 160 pounds, although there is much inequality as to details.

Bearing. The opposite end of the string is passed around a hitch pin in the iron frame. In order to transmit its vibrations to the sound-board the string passes over a wooden bridge provided with double raked pins, so as to give it a side bearing. At the end near the tuning pin the string

The Tuning-Pin. The tuning-pin is a stout steel rod almost uniform in diameter from end to end, and threaded with a light fine thread. One extremity is bluntly pointed and the other is squared off to receive the tuning-hammer and pierced for the insertion of the end of the string. It is customary to wrap the string around the pin in three or four coils.

The Bridges. The sound-board bridges carry the strings between pins set at an angle to each other, in such a way that each string is diverted from its line of direction and carried on from the bridge to the hitch-pin on a line parallel with the original line. The side-bearing thus given to the string is intended to ensure its tightness and steadiness on the bridge.

The upper bearing bridge sometimes is in the form of a separate stud or "agraffe" for each string, and sometimes consists of a ledge cast in the plate over which the string passes, to be forced down into a bearing position by a heavy pressure bar screwed over it. The object is to give bearing to the string. The "capo-d'astro" bar is simply the pressure-bar arrangement cast in one piece. The student will be well advised to study all these constructions on the piano at first hand.

The Tuning-Hammer. The tuning-hammer, with which the actual turning of the pin is accomplished, is a steel rod carrying a head bored to receive the pin. The hammer is placed on the pin. which is turned by pressure of the hand on the hammer handle in the required direction. There are many interesting points about the manipulation of the hammer, however, which must now be considered.

The mechanical problem relates to the turning of a pin acting under a combined tensional and torsional strain; in other words a pin which is being simultaneously pulled down, and twisted around. If the wrest-plank is well made, the pin will resist successfully both of these strains and when turned by the hammer will retain its new position. But in order that this should be so it is necessary to acquire a certain technique of manipulation.

Manipulating the Hammer. The implement used for turning the pins and known as the tuning-hammer is, by its very shape, susceptible of wrong use. It presents the constant temptation to manipulate it as if it were a wrench. The resistance that the pin and string impose against turning is sufficiently great to cause the novice nearly always to twist and wrench at the pin in the effort to turn it. Now, it must be remembered that the distance through which the pin is turned is so very slight that where it has been tightly driven, or presents any other obstacle to free turning, the hammer nearly always gives too hard a twist or pull, so that the pin, after sticking, turns too far. In an upright piano the tuner stands in front of the pins, which are about on a level with his chest, and his natural inclination of course will be to pull downwards and outwards on the pins whilst attempting to turn them, in such a way as to drag the lower surface of the pin against the bushing in the plate and so gradually wear away the bushing and the wrest-plank hole and finally loosen the pin altogether. In order to overcome these possible faults, the student will have to work out his own method of manipulation, bearing in mind always that his object is to turn the pin and not merely bend it. If he merely bends it he may alter the string tension enough to change the pitch as desired; but a smart blow on the piano key will soon knock the string back again where it was before. That is why young tuners do not tune "solidly." They do not turn the pins; they merely bend them. I shall offer the following sug-

is as it should be. In any case, the hammer should be held vertical, or still better, inclining slightly over to the bass side. The above applies to the upright piano only.

5. *And in Grand Pianos.* In a grand piano, to tune with the right hand is best on account of the position of the tuner with relation to the strings; which is opposite to the position with reference to the upright. But the highest treble strings, on account of the peculiar construction of the grand piano, are most conveniently tuned with the hammer held in the left hand.

6. *Tuning Pure Intervals First.* All intervals that are to be tempered should be first tuned pure and then raised or lowered.[1] Other things being equal, it is better to tune slightly above the required pitch and let the string slack back; which can be assisted by a smart blow on the key. Coaxing the string up to pitch usually involves its slacking off as soon as the piano is played.

7. *Strings Hanging on Bridges.* Strings often hang on the belly bridge and on the upper bearing. The waste ends at either extremity sometimes cause this trouble. The tuner must acquire the habit of so tuning that the string is pulled evenly

1 See page 96.

through its entire length, from tuning-pin to hitch-pin, maintaining the tension of all its sections uniform. To be sure that the pin is thoroughly turned gives the best assurance that the above requirement has been fulfilled.

8. *"Pounding" Condemned.* I do not believe in brutally pounding on the keys of a piano in an effort to "settle the strings." It is quite uncertain how much the strings can be "settled" in any way like this; and the process is objectionable in every other way.

9. *Muting.* The simplest way of muting the strings is by using a long strip of felt to stop off the outside strings of the triples and the alternate strings of the doubles, from one end of the piano to the other, before the tuning begins. Then the temperament Octave may be tuned on the middle string of each note and the Octaves up and down therefrom; after which the outside strings of the Unisons may be tuned all together. If however for any reasons such as those mentioned below, this causes the piano to stress unevenly, the Unisons can be adjusted section by section.

10. *Position at the piano.* All things considered it is better to stand up to tune all pianos, even grand pianos. The practice of sitting to tune up-

right pianos is certainly to be condemned, as it leads to slovenly handling of the hammer and general slackness.

11. *Raising Pitch.* In raising the pitch of a piano, go over it at least twice, the first time roughly, the second time smoothly. If the amount of rise required is very great the piano will need three tunings at once and another shortly after. Arrangements should be made with the owner of the piano in accordance with the extra amount of work to be done.

12. *On Old Pianos.* Raising the pitch on old pianos is always risky, as strings are likely to break. In emergencies, rust may be treated, at the upper bearing bridge and hitchpins, sparingly with oil. But oil is only to be used in emergencies, and with the utmost care to see that it does not reach the wrest-plank or soundboard bridges.

13. *Lowering Pitch.* In lowering the pitch, not less than three tunings will be required usually. This work is even more delicate than the above and needs even more care. The first tuning should be merely a rough letting down. Then the second may be a rough, and the third a smooth, tuning. But it is well to have an interval of a day between the second and the third tunings.

fault of uneven tension, make for strings that beat when sounded alone. This beating arises through sections of the strings being unevenly stressed, whereby the corresponding partial tones are thrown out of tune. Such uneven stress may be the result of a twist put in the wire during the stringing, or of uneven thickness of the wire. When false beats are encountered, sometimes the tuner will find he can neutralize the beats by tuning the string slightly off from the other two of the triple. If no such expedient will work, then the strings must be left alone. Such false beats are especially to be found in the upper treble.

18. *Bass Tuning.* The real fundamental tones of the lowest strings are not actually heard. We hear instead upper partials thereof. Hence it is very often impossible to tune bass octaves by mere audition of beats between coincident partials. In this condition of affairs the tuner may tune by testing the Tenths, which is a good plan, or by isolating some partial and testing it with the corresponding note above. To tune a clear bass is sometimes impossible.[1]

19. *Test Intervals.* All the tests recommended in the previous chapter should be used constantly

[1] Cf. the discussions in Chapters II, III and IV.

during the progress of the work, for the tuning will not be good otherwise. The most prolific source of imperfection lies in the accumulation of exceedingly slight errors; which soon mount up to intolerable mistunings. Constant testing, note by note, is therefore absolutely essential.

20. *Sharp Treble.* The temptation to tune the treble tones too high is one constantly to be avoided, for it is constantly present. Careful testing will alone rid the tuner of this error, which is insidious and habit-forming.

21. *Lastly:* Not twenty, but a hundred and twenty, rules or suggestions like these could easily be laid down; but I prefer to leave the subject here. The student will learn at least one more: the value of Patience.

"Style." The student will also determine for himself, as time goes on, the characteristics of what may be called his special "style." Tuning is an art and one which suffers more through being misunderstood than through any other single condition. The fine tuner is an artist in every sense of the word and the mental characteristics he must possess are such as not everybody can hope to have.

Understanding and Patience. Understanding and Patience are the foundation of the tuner's art and for my part I am not sure to which of these qualities I should award the primacy. Certainly it is true that without Understanding the tuner is groping in the dark; whilst without Patience he is already condemned in advance to failure in the attempt to do artistic work.

Experience. Experience too, is vastly important. The most talented student of the art finds that there is a mechanical technique to be mastered in tuning, just as in playing the piano. The necessary delicacy of wrist and arm, the necessary intuitive feeling that the pin has been turned as it should be; the necessary exquisite delicacy of ear:[1] all these faculties are the product of patient experiment and practice. The novice cannot expect to possess them; nor can he have any reason for being disappointed when he finds, as he will find, that to gain anything worth gaining, one must work—and work hard.

1 "Delicacy" here means rather "power of discrimination" than mere intuition. What is usually called a "musical ear" is nothing more than, at best, a feeling of tonality sometimes extending so far as unaided recognition of individual tones and tonalities on hearing them; and at worst, an inclination towards simple melody, harmonically bare. The tuner's audition is acoustical, not artificially musical. The ordinary "musical ear" is of little value to him.

CHAPTER VI.

THE MODERN PIANO.

Scope of this Chapter. The piano is the most familiar of musical instruments and one of the most accessible for purposes of examination. In the following pages, I shall assume that the reader has a piano at hand and will follow me throughout, with it as a model. Such a method will be found more satisfactory than if I asked the student to follow me with the aid merely of a few illustrations. I shall not undertake any critical examination of the details of piano construction, for this is the province of a special technical treatise,[1] but shall confine myself to describing the features of the modern piano in a manner calculated to be of the greatest assistance to the tuner and repair man.

An Instrument of Percussion. The piano is a stringed instrument; and to this extent belongs

1 "Theory and Practice of Pianoforte Building," by the present writer.

to the same general family as the violin. But its strings are excited by blows inflicted directly by a hammer and indirectly, through a mechanism called the "action," by the performer's hand. Hence the piano is also an instrument of percussion and belongs to the same general family with the dulcimer, the xylophone and the drums. This last fact is of great importance, for it is impossible to understand the peculiarities of the piano unless we entirely forget its incidental likeness to other stringed instruments and concentrate our ideas upon the outstanding fact of percussion as the cause of the sounds evoked by it.

Upon the fact that the strings are violently *struck,* instead of being bowed or plucked, rests the entire character of the piano, making any comparison of it with the violin or other stringed instrument absurd. This is especially true with regard to the sound-board.

Three Elements. The piano proper comprises three elements; the scale, the sound-board and the hammer-action. All other parts are entirely incidental and accessory.

Scale. The *scale* of the piano consists essentially of the set of strings which are struck by the hammers. There are eighty-eight digitals in the key-board of the piano and thus eighty-eight separate tones. The strings are grouped three to an unison throughout some five octaves of the range, and thence in double grouping (2 to a note) downwards to the lowest bass. The last ten or twelve at the lowest bass extreme are usually single strings.

Now it will be understood that the strings of the piano increase in length and weight as the scale descends. The highest note on the piano (C_7) is evoked by a string some 2 inches long, and this length rather less than doubles at each octave descending, until the lengthening process is brought to a stop at the size limits of the piano. This lengthening increases the weight of the descending strings until at about five octaves below C_7, it becomes necessary to shorten the remaining strings between this point and the extreme bass on account of the size limits mentioned above. The requisite slowness of vibration therefore must be had by over-weighting the shortened strings; which is done by covering them with iron or copper wire. This covered section is usually strung cross-ways over the treble strings and is therefore called the overstrung section.

Now the immediate point is that the main-

upper extremities of the strings and which the tuner turns when adjusting the pitch of the piano; "tuning the piano" as we say.

The iron plate covers the front of this massive wooden back, and the sound-board is fastened to the back with the iron plate over it.[1]

Grand Piano: Plate and Back. The supporting structure of the grand piano is somewhat different. In the upright the sides and the casing generally are simply attached to the fundamental structure known as the back. But in the grand piano the whole case is glued around a rim of cross banded veneers which in turn encloses another rim, into which runs the system of braces and struts which comprises what corresponds to the upright back and on which sound-board and plate are laid.

First-hand study of pianos in grand and upright form will reveal all these matters to the student clearly.

Sound-Board and Bridges. The sound-board of the piano is the resonating apparatus which amplifies and modifies the string-sounds, so as to endue them with the characteristics of piano

[1] The method of gluing the sound-board to the back and all similar technical details may be found described in my "Theory and Practice of Pianoforte Building."

tone. It is an open question how much influence the sound-board exercises in the development of tone. My own theory has been for long that the sound-board is a true vibrator and the direct producer of the piano tone; and that the string acts rather as the selector, imposing upon the board the particular wave-form which its own vibration evokes.[1]

From the tuner's point of view, the chief present interest of the sound-board lies in its physical character and its behavior under use. Even a cursory examination of the sound-board and of the bridges which cross it carrying the strings, indicates clearly that two essential conditions must exist if the board is to perform its resonating duty well. The strings must be maintained on an adequate up-bearing and side-bearing, whilst the board must be in a state of tension. The board must be resilient, but also stiff, in a sense. It must be arched upwards to maintain itself against the immense down pressure of the strings, but also it must be built so that the necessary arching will have no injurious effect upon the wood-fibres, with consequent splitting or crack-

[1] This matter is further treated in the following chapter. Cf. also, "Theory and Practice of Pianoforte Building," pp. 58 *et seq,*

ing. It will easily be seen then that the sound-board of the piano is a structure of exceeding delicacy, called upon to perform difficult and laborious duties.

The strings are carried over the sound-board on two wooden bridges, one for the overstrung bass and one for the remaining strings. It is customary to construct these bridges of cross-banded hard maple veneers, to avoid splitting. The strings in their passage across the bridges are given side-bearing by means of suitably driven pins. These bridges are glued on to the sound-board and secured from the back thereof by means of screws.

Ribs. The sound-board is ribbed with strips of the same lumber (spruce) which is used for the body of the board. The object of ribbing is (1) to facilitate the impartation of a proper curve, or arch (called usually the "crown") to the board, (2) to impart tension to the board and (3) to strengthen it against the string-pressure. Ribs are usually 12 to 14 in number and cross the board diagonally, from the top of the treble to the bottom of the bass, side.

The above description applies equally well to grand or upright pianos.

the nature of its material as to density, etc., and the arc of travel through which it turns, together with its velocity, are the controlling factors in tone production. This turning of the hammer in obedience to the depression of the piano key is the province of what is called the "Action" of the piano.

Action. The "action" of the piano is the mechanism interposed between hammer and performer. It consists essentially of a set of digitals or finger-keys, one for each tone in the compass of the piano, and an equal number of lever-systems, consisting of levers turning in arcs of circles, one to each key, operating the hammer. When the key is depressed, the hammer is thrown forward, trips before it touches the string, is carried to the string by its own momentum, and instantly rebounds. The string is allowed to vibrate so long as the key is depressed.[1]

Damper Action. The so-called "damper" is a piece of molded wood faced with soft felt, which presses against the string, but is lifted away therefrom as soon as the key is depressed. The damper allows the string to vibrate freely until

[1] Cf. Chapter VIII for complete discussion of these points.

the key is released, when it at once falls back on the string and silences it.

For the purposes of artistic piano playing, however, it is necessary very often to take advantage of the sympathetic resonance of the sound-board by allowing the tone emitted by one or several string-groups to be strengthened, colored and otherwise enriched by the simultaneous sounding of other strings whose fundamentals are true partials to the originally sounded strings. When the entire line of dampers is lifted from the strings and held away from them by suitable mechanism, this property of the sound-board comes into play, and the warm color thus imparted to the tone constitutes one of the most valuable elements in piano playing.

In order to permit this advantage, the line of dampers is adapted to be pushed back from the strings (or in the grand piano, lifted up from them) by means of a rod actuated by a simple lever system which terminates in a "pedal" operated by the right foot of the performer. This lever system is called the "trap-work" of the piano and is situated under the keyboard in the grand piano, with the pedals arranged in a frame-work known as the "lyre"; whilst in the upright the pedal and trap-work are placed at the bottom of the piano on what is called the "bottom-board." The pedal is convenient to the performer's right foot and is called the "sustaining pedal"; sometimes, wrongly, the "loud pedal."

Soft-Pedal. In the grand piano the keys and action are put together on a frame which can slide transversely. By depression of a second pedal the action is slid towards the treble, so that each hammer strikes only two strings of each triple, and one of each double, group. The effect is to soften the tone and modify its color. Similar trap-work is used between pedal and action, placed alongside the sustaining pedal action. The second pedal is placed conveniently to the performer's left foot and is called the "soft pedal."

In the upright piano the arrangement is the same except that instead of shifting the action, the hammers are pushed forward closer to the strings by a rod which rotates the rail against which the hammer-shanks rest.

Sostenuto or tone-sustaining pedal. On grand pianos, and occasionally on uprights, is to be found a third pedal situated between the other two

Trusses: Resting on Toes and holding up key-bed. Sometimes called the "legs."

Fall-Board: The folding lid over the keys. The double folding type is now usual and is called the "Boston" fall-board. The older type or single lid is called the "New York" fall-board.

Shelf: Laid over fall-board to support music.

Name-Board: Resting over keys to support single type fall-board.

Key-slip: Strip in front of keys.

Key-Blocks: Heavy blocks at each extremity of keyboard.

Top-Frame: Folding or fixed frame, often elaborately decorated, which supports music and conceals piano action and hammers.

Bottom-Frame: Similar frame to the above, covering trapwork and parts of piano under key-bed.

Pilasters: Decorative pillars sometimes placed on either side of top-frame to support it.

Top: The folding lid which covers top frame and finishes off the casework of the piano.

Bottom-Rail: Rail running across the bottom of the casework, in which the pedals are housed.

Bottom-Board: Board on which trap work is mounted, behind the bottom-frame.

Names of External Parts. Although the piano is such a familiar article there is a great deal of confusion as to the names to be applied to its

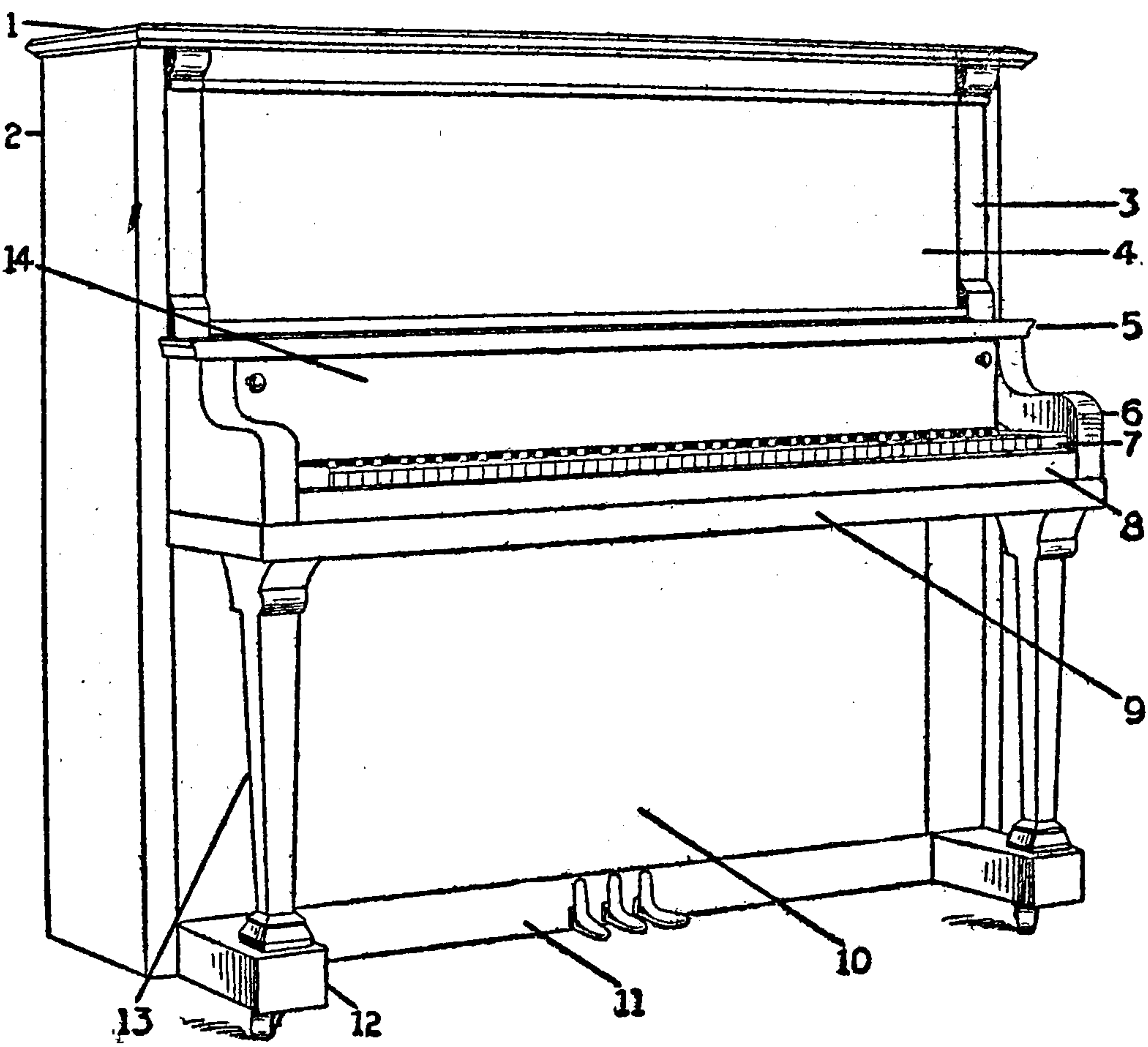


FIGURE 15.

1. Top.
2. Side.
3. Pilaster.
4. Top Frame.
5. Shelf.
6. Arm.
7. Key-Block.
8. Key-Slip.
9. Key-Bed.
10. Bottom Frame.
11. Bottom Rail.
12. Toe.
13. Truss.
14. Fall Board.

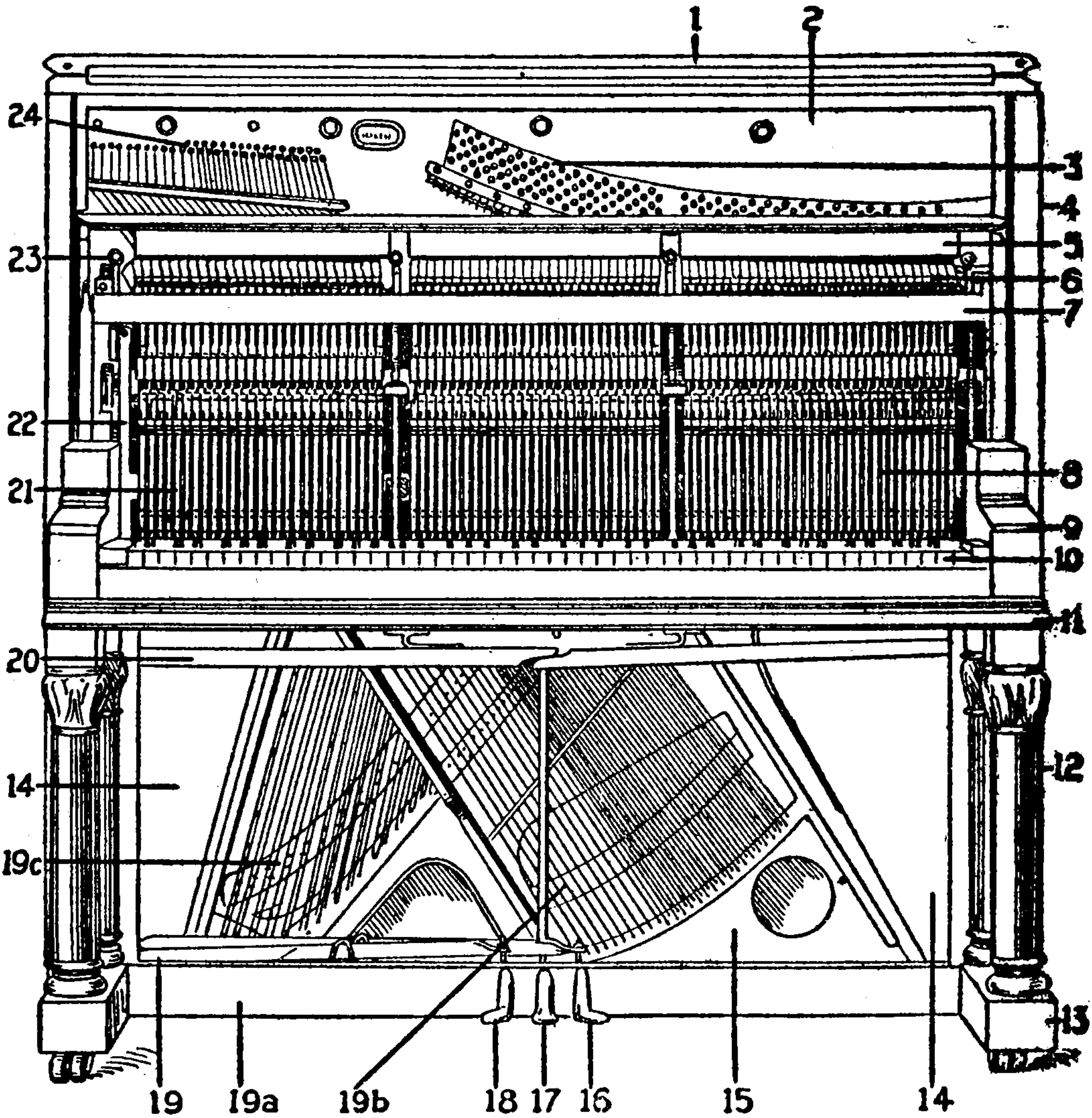


FIGURE 16.

1. Top.
2. Iron Plate, covering wrest plank.
3. Treble tuning-pins.
4. Side.
5. Muffler-rail and muffler felt.
6. Hammers.
7. Hammer-rail.
8. Action.
9. Arm.
10. Digitals or Keys.
11. Key-Bed.
12. Truss.
13. Toe.
14. Sound-board.
15. Iron Plate.
16. Sustaining Pedal.

7

Figure 17.

1. Top Block of Back, behind wrest-plank.
2. Limiting Rim of Sound-board.
3. Posts.
4. Ribbing.
5. Surface of Sound-board.
6. Bottom-rail of Back.
7. Limiting rim of Sound-board.

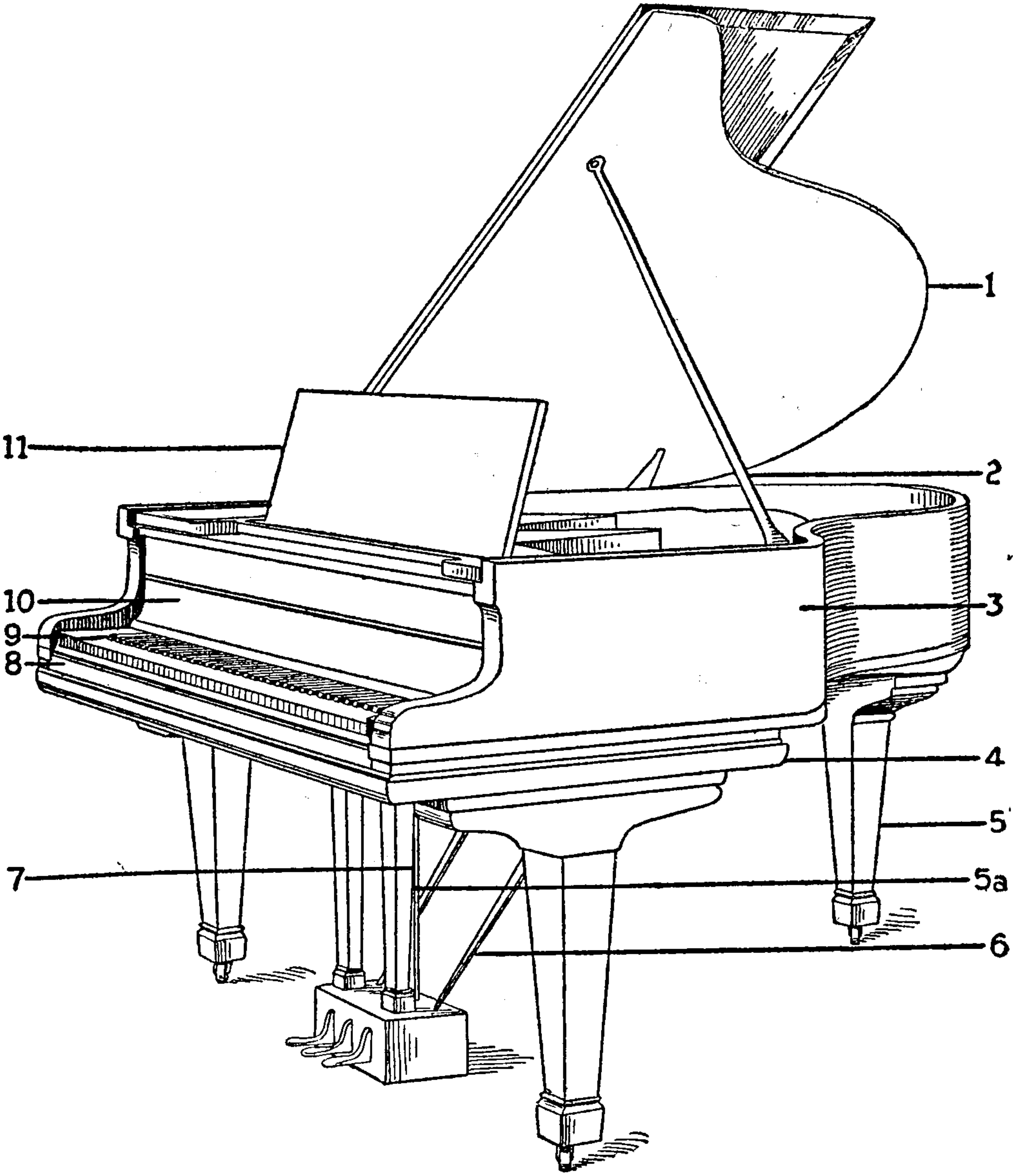


FIGURE 18.

1. Top.
2. Top-Stick or Prop.
3. Case.
4. Key-Bed.
5. Leg.
5a. Pedal-Frame or Lyre.
6. Pedal Frame Brace.
7. Pedal Rod.
8. Key-Slip.
9. Key-Block.
10. Fall-Board.
11. Music Desk.

Materials Used in Piano Construction.

Materials	Used In
Woods:	
Mahogany.	Veneers for Cases.
Walnut.	Veneers for Cases.
Oak.	Veneers for Cases.
Circassian Walnut.	Veneers for Cases.
Bird's Eye Maple.	Veneers for Cases.
	Veneers for Cases.
Maple.	Wrest-Planks. Backs. Hammer moldings and shanks. Hammer rails, dowels, etc.
White Wood.	Body of case work.
White Pine.	Key Frames and keys.
Spruce.	Sound-boards.
Pear. Holly. Sycamore. Cedar. Mahogany.	Various small action parts.
Leathers:	
Doeskin. Elkskin. Buckskin.	Various action parts.
Felt and Cloth:	
Green and White Baize.	Key-rail cloth, punchings.
Tone Felt.	Hammers.
Damper Felt, hard.	Bass dampers.
Damper Felt, soft.	Treble-dampers.
Flannel.	Casework punchings, fall-board strips, name-board strips, stringing.
Ivory.	Tops of white keys.
Celluloid.	Fronts of white keys.
Iron.	Iron plate, action brackets, bolts and general hardware.
Steel.	Action angle rails, plates, trap-work springs, etc.
Brass.	Action-springs, pedal feet, rods,
Graphite.	Lubrication of action, etc.

chapters of certain elements which the tuner requires to understand in completeness and the present chapter will be perhaps most useful in providing a convenient peg on which to hang them. Although it fulfills so humble a purpose, however, it will not be without its value if it impresses on the reader's mind the great truth that the piano, as it stands, is by no means to be regarded as the fruit of sudden inspiration but rather as the contemporary stage in a long process of evolution. The history of the instruments which preceded the piano in point of time, and which in system are its ancestors, shows plainly that the invention of the hammer action by Cristofori in 1711 was merely the culmination of a long series of efforts on the part of many great craftsmen, looking towards the production of a musical stringed instrument capable of doing for domestic use what the organ has always done for the church; namely, furnish complete command over all existing resources of harmony as well as of melody. The piano as it stands to-day is the crown of three centuries of endeavor; but it is by no means certain that it will not yet be modified much further. No one can pretend that the piano is a perfect instrument. Its tempered intonation, its rather hard unmalleable tone, its lack of true sostenuto, all represent defects that must in time be improved out of existence. Meanwhile, we have to take the piano as we find it, realizing that after all it is a very fine and very wonderful instrument.[1]

Incidentally, it is a matter for congratulation that the modern development of the piano is almost wholly an American achievement; and that European makers are confessedly inferior to the best of their American colleagues. Why this should be so is another matter; but it certainly is so.

[1] The reader who desires to study the extremely fascinating history of the piano may find an extensive literature on the subject. Hipkins is the best authority by all means. See bibliographical note at the end of this volume.

Chapter VII.

SOUND-BOARD AND STRINGS.

Quite as characteristic of the piano's individuality as the hammer action itself, is the apparatus of resonance, or, as we more usually call it, the sound-board. The piano is a stringed instrument and thus claims kinship with viols and lutes and all their descendants; but ever so much more it is a resonance instrument and a percussion instrument. In fact, the true character of the piano cannot be rightly apprehended until we have realized that the string-element is really overshadowed to a considerable extent by the sound-board. The piano is just as much dependent upon resonance as upon the prior vibration of the strings. Without the sound-board the piano would have neither power nor color to its tones. Moreover, variations in the quality of the sound-board material in its construction and in the skill of its design involve parallel variations in the tonal values of pianos, of such marked and distinct charac-

piano construction as they affect the piano tuner in his work, the pianist in his playing and the piano in its durability and value.

Definition of tone-emission apparatus functions. The object of the tone-emission-apparatus may be described as follows: to produce the characteristic piano tone, through the vibration of the strings in response to the percussive action of the hammers thereon, and through the resonating functions of the sound-board, whereby the original string wave-forms are combined, amplified, and transformed in quality as required for the purpose indicated.

That is not a neat definition perhaps, nor is it uncommonly accurate in all its parts; but for the present it is perhaps the truest description that can be assimilated. Later on we shall improve and refine the details with better understanding.

Piano Tone. The feature of the piano which distinguishes it generally from all other musical instruments, and specially from all other stringed instruments, is the peculiar character of its tone. This is, to an extent, of course, hard and unmalleable. It possesses neither the plasticity of the violin tone nor the bitter-sweet gayety and lightness of the guitar. It is solid, yet evanescent, hard yet capable of infinite gradation in intensity. Lacking the serenity and majesty of the organ diapason, it is pre-eminent in obedience to touch. The pianist cannot indeed sustain his tones, nor swell or diminish them at will. Here both organ and violin surpass the piano. But the pianist can color his tone almost as widely as the violinist, and withal has a touch control over dynamics which the organ entirely lacks. Thus the tone of the piano, as brought forth by a good performer, has qualities highly attractive, which, combined with the convenience of the instrument, its capacity for complete musical expression in all possible harmonic relations, and its moderate price, have made it supreme in popularity. Let us then see just how this peculiar tone is produced.

Acoustical Definition of Piano Tone. Speaking from the view-point which we have adopted in Chapter II, it may be said that piano tone is the effect of a wave-form induced by hammers striking upon heavy high-tension stretched strings at pre-determined points on the surface thereof; these waves having definite forms which are modified by the resonating power of the sound-board. The first important feature is that the piano tone is produced by the strings being *struck;* thus distinguishing the piano from all other stringed instruments.

The string is struck. As we have already found out [1] a string stretched at high tension and struck by a piano hammer, is thrown into an extremely complex form of vibration. This vibrational form consists of the resultant of a number of simple forms, which in turn are the effect of the string's vibrating in various segments as well as in its whole length. In short, the fundamental tone of the string, together with partial tones corresponding to at least the following five divisions,[2] sound together whenever the hammer makes its stroke. The exact number of concomitant partials depends, partly upon the amplitude of the vibration, which depends in turn upon the intensity of the blow, partly upon choice of the point of contact of hammer on string, and partly upon the stiffness and weight of the string.

"Touch." "Touch," of course is an important element in the control of the exact shape of the wave-form. Tone-color or character, as we are aware,[3] depends upon the wave-form, and

1 *Supra*, Chapter II.
2 See Chapter II, "Resultant Motion."
3 Cf. Chapter II.

termediate doors being stopped off so that ordinarily no sound will come from one room to the other. If the open end of the rod be now brought into contact with the sound-board of another piano, leaving the dampers of this second instrument raised, the tone of the first piano when played will be reproduced note for note but in diminished volume, from the surface of the second sound-board. The same experiment may be made by using a violin as the "receiving instrument." This experiment shows that the sound-board of the piano has independently the power of vibrating in all the extraordinary complex of motions that arise, not only as the resultant wave of the complex motion of one string, but as the combined resultant—the resultant of resultants—of the motions of many simultaneously excited strings. The motion of a string may be compared with the operation of several forces pulling in different directions. The resultant of these forces—that is, the direction in which the net value of all the forces when compounded, is seen to lie—can be determined mathematically. So also we know that the complex vibration of one string combines into a single complex or resultant curve.[1] And so also

1 *Supra*, Chapter II.

we can see that the complex vibrations of two strings, if impressed together upon a sound-board, must combine into a further resultant; a process which can be carried on indefinitely. Thus, whilst we see on the one hand that the sound-board must be capable of complex forms of motion, we can also perceive that the mechanical realization of such forms is neither inconceivable nor even particularly difficult to apprehend.

Analogy of the Monochord. If the suggestions I have made here have any value, they must tend to give us a reasonably clear conception of a theory which may account for the peculiar operation of the sound-board and may fix definitely its place in the economy of the piano. If, in fact, we keep steadily in mind the truth that no matter how many strings may be struck at any given moment, nor how consequently complex their motions may be, these motions always must express themselves on the sound-board as a single resultant motion, it becomes clear that such resultant motion is responsible for the tone; and nothing else.

In the circumstances, we may, without unduly stretching the comparison, suggest an analogy with the monochord. This, as we all know, is a single string stretched between a hitch pin and a tuning pin over a small sound-board, with a moveable bridge which can be shifted so as to change the vibrating length of the string whenever and however desired. Now, this string has in itself the possibility of producing all the tones which can be had by shifting the bridge. No matter how the bridge be placed and therefore no matter what segment of the string be vibrating at any time, it is the same string. The same string vibrates always, but the moving of the bridge *selects* the particular segment which is affected. So also with the sound-board and strings of the piano. The sound-board is a true vibrator, whose operations are representable as resultant motions of the string vibrations. The strings are selecting vibrators, impressing their own individual vibrations upon the sound-board, either singly or in combination. When a single impression is made, the board repeats the motion exactly as transmitted to it. When a complex of impressions is made, this develops instantly into a resultant motion, compounded of all the motions; or as we might better say, being the geometrical sum of all the motions.

Sound-Board a True Vibrator. If this be a plausible hypothesis, from the mathematical view-

central telephone station, while the strings are respectively the various subscribers' entering and outgoing lines. The strings are the nerves, the board is the brain. A dozen analogies suggest themselves. But, in any case, we cannot stop here. We must know how the board can receive the impressions which are transformed into resultant motions. What, in fact, is this Resonance?

Resonance is the property which sonorous bodies possess of impressing their vibrations upon other sonorous bodies. In the case of the tone-emission apparatus of the piano, the sound-board is placed in contact with the battery of strings stretched above it, which pass over wooden bridges glued on the surface of the board, pressing upon these latter with a heavy down bearing. The strings are brought over the bridges between pins which impart to them also a side-bearing as they cross. Thus it may be seen that the sound-board is in the most favorable condition to receive any vibrations that may originate in the strings. If it can be shown that the vibrations of a string can actually be imparted to the sound-board, and can cause that apparatus to undergo a resultant vibratory motion compounded from these vibrations, then we shall have the theory of the sound-board demonstrated.

Now, since resonance is a property possessed by all substances which may form sonorous bodies, it will be understood that we are not here discussing any uncommon quality of the piano sound-board. Seeing that the physical nearest cause of sound sensations is the performance of vibratory motion by solid bodies, it follows that resonance must take place wherever that vibration can be transmitted. If then we have a body of some material thrown into vibration, it is easy to see that all other bodies of similar material in contact with it must also vibrate. Whether their frequency is the same as that of the original body depends upon the comparative masses and other qualities of the two. All elastic substances are capable of transmitting vibrations, themselves partaking of the vibratory motion in the process; and so also if the two bodies in contact be of different material, it follows that vibratory motion may be transmitted from one to the other, so long as both be elastic enough and contact be maintained. Actual physical contact, indeed, may sometimes, under favorable conditions, be eliminated, and the atmosphere alone be competent to transmit the pulse from one body to the other, as it does from the body to the ear. This latter potentiality is translated into fact only when each of the bodies is very favorably situated for the purpose and extremely sensitive to vibratory impulse. The resonance boxes of two adjacent tuning forks furnish an example of these latter qualities.

We see therefore that there is no mechanical or physical reason why the sound-board should not at least *receive* the vibrations of the strings. The question therefore becomes this; does the sound-board reproduce them after it has received them; and how?

Composition of Impulses. We have already seen (*supra*) that the most satisfactory hypothesis of the sound-board's functions is that which considers it as a true tone-maker; but the mind does not always grasp easily the idea of the apparently stiff and unresponsive sound-board reproducing and amplifying the complex vibrations of the strings. Yet a simple illustration will show that this is quite possible.

Suppose we secure somewhere a heavy ball, or a metal weight, like a ten pound scale weight, and suspend it from a cord so as to form a pendulum.

be delivered at the rate of one per second until, say, 160 of them have been made, the resistance has been operated on with a force, at the end of 160 seconds, equal to a force of ten pounds (160 ounces), operating through one second. Thus we see also that it is quite possible for even the most delicate and minute vibratory motions not only to be imparted to a stiff sound-board but also to throw that board into resultant motion. For if we consider that the middle tones of the piano are produced by frequencies running from 200 to 800 vibrations per second we can easily see that what is possible in the extreme case here described is more than possible—nay, is inevitable—in the case of the specially prepared, highly elastic and tensioned sound-board, especially when we remember that the strings, being struck, are set in relatively violent agitation, and communicate a relatively more powerful vibratory impression than can be had by blowing with the breath, on a far more responsive resistance than the weight, and at many times the possible blowing speed.

Considerations like these, although they do not actually demonstrate the hypothesis of sound-board behavior here adopted, do strengthen it and tend to confirm it.

To sum up, we may say that the sound-board and strings of the piano together constitute the tone-emission apparatus, that the sound-board is the main vibrator or tone-maker, that the strings are the selecting vibrators, and that the vibrations of the sound-board are resultant single vibrations due to composition of the complex of vibrations proceeding from the strings, just as the latter themselves are resultants of the complex of segmental vibrations which take place in the string when it is struck. I do not claim for this hypothesis that it is above criticism, but I am certain that it meets the facts more fairly than any other I have yet seen.

In making this analysis I have wished to prepare the reader's mind for the critical examination of sound-board construction, and especially to show reasons for some of the peculiar methods that characterize that construction and have been worked out by piano makers experimenting often in the dark. The problem of practical construction is to provide a resonance table that will not merely take up in resultant vibration the impressed vibrations of the strings, but also will properly amplify these as well as reproduce their forms. In other words, it is not enough for the sound-board to reproduce the characteristics of the tone, but to amplify it; make it loud enough. We need quantity as well as quality.

Amplification. Amplification of the wave-forms is of course a natural consequence flowing from the large mass of the sound-board and the consequent relatively great mass of adjacent air which can be put in vibration. The tones originally impressed by the wave-forms of the strings are therefore intensified.

Coloration of Tone by the Sound-Board. We know that inasmuch as most piano strings are struck well above the seventh node, the seventh partial is a definite member of the partial tone procession in the piano string's wave-form. The presence of this partial tone, however, is, on a thoroughly well-made piano at least, scarcely perceptible in its influence on the tone color, although when it is markedly present in any other tonal combination, its tendency to promote harshness is at once discerned. This partial and its multiples, as well as the ninth and others above it which are not eliminated in the upper regions of the piano on account of the high striking point, would have a much more distinctly hardening effect on the tone than is the case, if it were not for

of compression and partly of tension. Hence the whole structure has its own regular period of vibration and its own proper tone.

The object of sound-board design therefore must be to take advantage of the proper vibration of the board, plate and back together, and to see that the relative importance of each element is retained, without any one being unduly prominent. The fact is, of course, that since the sound-board is the true tone-maker, and since the iron plate and back are in such close contact with it, each of the two latter exert a constant modifying influence on the vibratory activity of the board. In short, the various materials of which the back-structure (board, plate and back) are made, all exert their individual influences, so that the ultimate vibratory period and composition of the wave-form proper to the sound-board arises out of all these forces compounded. Hence the question of the dimensions and design of each of these elements is almost equally important.

I have made this digression because it is important that the tuner should understand the reasons for differences in tone-quality as between various pianos. I shall not go into small detail regarding the design of these elements because that is the province of a technical treatise on piano construction and has been treated elsewhere.[1] The following remarks are appended, however, treating generally of the influence of the parts mentioned.

Influence of the Iron Plate. The cast iron of the plate is of course considerably stiffer and more rigid than wood. Its weight-for-bulk is also much greater; or, in other words, its specific gravity is represented by a higher index. Now it is well known that the vibratory form of any body which is enough under tension to induce susceptibility to vibrative influences is modified by the factors of density and rigidity. On the whole, any increase in density and rigidity tends to produce a wave form in which the higher partials are undamped. The more "yielding" structure of wood, as it were, has a damping effect on the less powerful partials, or rather, perhaps, is incapable of so elaborate a subdivision under the influence of the string vibrations. Hence the wood of the sound-board will, if left to itself, act as a damper on all the feebler partials of the strings, however many may have been left after the rebound of the hammer. The tone quality, there-

[1] Cf. "Theory and Practice of Pianoforte Building."

fore, is founded on a partial-tone series scarcely extending above the eighth, with perhaps a trace of the multiples of the even numbered partials. Iron, however, modifies this procession by taking up the higher partial vibrations of the strings and reproducing them in amplified form. At least this is the most plausible explanation of the plate's activities, for it is certain that the more iron we have in close touch with the strings, at the extremities and on the bearings thereof as well as around the sound-board area, the harder and more "metallic" is the tone; which of course means the existence in the tonal complex of high dissonant partials. Thus it is plain that the iron plate should be so designed as not to overload the structure, and especially so as not to usurp all the functions of bearing. Wooden upper-bearing bridges are often useful in a piano which otherwise would produce a harsh and metallic tone. Excessive bracing or barring and undue massiveness are also bad features. In fact, we may say that the plate should be as light as possible; the lighter the better so long as it is strong enough to stand the string strains. This of course greatly depends on the precise tensions at which the strings are stretched, which again depends on the dimen-

cessful solution of this problem, unless I am much mistaken.

Dimensions of the sound-board. The sound-board is limited, of course, according to the size of the piano, and therefore no particular rules can be given for length and breadth, or even for shape. It is to be observed however that the size of the piano and the tension and other features of the scale will require parallel modifications in the size and thickness of the board; that is in the vibrating area. But this is a matter which, in the nature of the case, must be determined by experiment. The point is that the board must be free to vibrate, in the particular situation created by the other conditions of the piano. If it is too heavy it will vibrate feebly on light playing, whilst with heavy playing its vibratory form will incline to be too much in its own proper period, thus smothering the resultant vibrations selected by the strings. If it is too light it will respond in light playing too readily and so again its proper vibration will intrude, whilst on heavy playing it will be unable to respond strongly enough to provide sufficient support to the strings. Thus the thickness must be graduated to the size. In practice piano makers have found it well to vary the thickness of the board between the two extremities. Thicknesses running from ⅜″ in the treble to ¼″ in the bass are usual. But these are experimental matters and can be determined only experimentally.

Ribbing. The sound-board must be ribbed in order to stiffen its surface and enable it to resist the various strains put on it. These strains are (1) the down bearing of the strings; (2) the tension of the strings; (3) the opposed tension and compression of upper and under surfaces due to the crowning. The crown is necessary in order to give a proper bearing and also to resist the downward pressure.

It is likewise useful in promoting the necessary tension for free vibration. The ribs are planed into curved surfaces where they are glued on to the board, so as to produce the crown, which also is further promoted by being glued on to slanted "linings," as they are called, in the back structure. It is customary to use from 12 to 14 ribs and these should be placed so as best to sustain the strains without being too heavy or having too much of a damping effect. No other rules can or need be given in this book.[1]

[1] For a general discussion of these points cf. "Theory and Practice of Pianoforte Building."

Bridges. The position and curvature of the bridges are entirely governed by the string design. No special descriptions therefore need be given here, except to remark that it has become customary to build up the bridge structure of cross banded veneers of hard wood, so as to avoid any tendency to split. The pins, which are driven into the bridge to give side-bearing to the strings, represent an archaic survival from past days, in fact from the days of the harpsichord, and there is no doubt that it would be a great deal better to use an agraffe, or drilled metal stud, such as is found on the upper bearing bars of grand pianos (and in some uprights also). False beats in strings are often generated by faults in the pinning, whereby twists in the wire are produced.

The bridges must be high enough to give a good down bearing and wide enough for a good side bearing. They should never be cut to permit the treble brace on the plate to pass through, but the plate design should be modified accordingly. A cut treble bridge always means a bridge that does not transmit the string vibrations properly to the bridge, and invariably involves bad tone, and rapid break-down. The greatest enemy to the conservation of piano tone is the degenera-

amplify. The wave-form must first be created by the string vibration; and therefore the dimensions, weight and method of stringing are of the utmost importance.

String Dimensions. Elsewhere I have made a tolerably complete study of string dimensions,[1] and here, therefore, I may be brief. The proportion of pitch from octave to octave is as 1:2 but since strings have weight and weight increases with length, this proportion will not hold good in designing string lengths. Piano makers, attempting to compensate for the factors of weight and tension, have produced various scalings of string length ranging from the proportions 1:1.875 to 1:1.9375 for each octave. In other words, instead of doubling the string lengths at each octave, each string is made 1⅞ or $1\frac{15}{16}$ as long as its octave above. Intermediate lengths should be worked out, one by one, in proportion. Practice dictates almost universally a length of 2 inches for the highest treble strings.

Gages. It is a very clumsy and altogether unpardonable sin to change the gages of wire used in a scale when putting on new strings, unless it is obvious that some fatal defect in tension propor-

[1] Cf. "Theory and Practice of Pianoforte Building," p. 48 *et seq.*

tions exists. Evenness of tension is a desideratum always aimed at, but not often attained; mainly through lack of inclination to calculate closely. But the tuner should very carefully follow the gage of wire when re-stringing, for it is usually to be taken for granted that the piano as strung represents the best gaging that could be devised, considering its scale. The wire sizes used in piano making range from gage 12 (sometimes used in the highest treble), down to gage 26 for core wire on the heaviest bass strings on large pianos. In determining what string gages to use, piano makers should attempt to obtain an even pull for each string from end to end of the scale. On the whole, the average strain of 160 pounds per string, which is common to the mass of American pianos, is too high, and a general lowering of gage would be a good thing in all probability. The high tension piano has never fulfilled the promises so lavishly made for it thirty-five years ago. Heavy wire means higher tension. Tensions are already too high, which simply means hard, thin, metallic tone, superficial glitter and coldness. The modern piano already has much to answer for in this respect.

Striking Point. This is another matter not always considered with sufficient care. In a good piano the point at which its hammer touches each string is chosen scientifically, for there is no more important detail in piano design than this. I have already discussed this subject in an earlier chapter (Chapter II), but it may here be observed that the tone quality of a piano is very closely associated with the position of the hammers in relation to the strings. The tendency in modern pianos is to make the striking point excessively high. For my part I should like to see a return to the ancient fashion of low tension strings and low striking points. Of course, as we all should realize by now, the necessary tonal re-inforcement of the short upper strings must be brought about by raising the striking point. But this point also is treated elsewhere (Chapter II). Commercial pianos take all these things for granted with a refreshing but somewhat disastrous naïveté however, and it is to be hoped that readers will realize that in these details and the care that is taken over them rests the difference between good and bad piano making.

Bass Strings. The use of steel, brass or copper winding for the purpose of overweighting strings artificially, so as to make up for necessary

climates gets covered with verdigris, perhaps more quickly than the tinned steel wire rusts; but I doubt whether the difference in favor of steel is enough to justify any preference, especially as, for the reasons above noted, copper is tonally better. The so-called "iron" covering wire is to-day usually a soft steel wire.[1]

To sum matters up, it may be said that the following points are important in any consideration of a string scale.

1. Accurate proportioning of lengths, measured string by string.

2. Careful graduation of wire thickness to assure equality of tension from one end of the scale to another.

3. Placement on the bridges with enough space for each string to vibrate freely.

4. Avoidance of grounding bridge extremities right on the edge of the sound-board.

5. Avoidance of too much iron on bearing bridges.

6. Accurate weighting of bass strings.

In setting down these facts about the string

[1] But the subject is highly controversial, as the discussions of the Chicago Conference of Piano Technicians in 1916 plainly showed.

scale, I have purposely avoided going into complete details; partly because the vibrations of a piano string and the details of stringing have already been treated in this book, and partly because I have elsewhere, in a volume still in print, also discussed them quite thoroughly.[1] From the tuner's view point all other necessary information is to be found in preceding chapters. The discussion of the sound-board has been purposely more complete because accurate information regarding its functions is not so readily available. Practical details are discussed in the chapter on piano repairing (*infra*).

[1] "Theory and Practice of Pianoforte Building," p. 28 *et seq.*, p. 48 *et seq.*, etc.

Chapter VIII.

THE ACTION AND ITS REGULATION.

The movement or "action" which translates the motion of the finger-impelled key of the piano to the hammer, has been developed within the past fifty years to a high state of perfection. Fundamental work was mainly done in Europe, where Erard established the principle of double repetition which distinguishes the modern grand piano, and Wornum devised the tape-check which makes the upright action efficient in repetition and reliable in attack. Although these revolutionary inventions date back about eighty years from the present time (1917) the enterprise of contemporary makers was unequal to any immediate recognition of their superiority, so that for a long time both grand and upright pianos were fitted with less efficient movements; until the example of the more courageous amongst them, especially in the United States, showed quite unmistakably the immense superiority of double repetition and the

blow thereon, (2) to trip the hammer immediately before its actual contact with the string, so that it instantly rebounds without blocking the vibration, (3) to permit the repetition of the hammer blow without complete release of the key and (4) to damp the string vibration immediately the key is released. These functions are of course identical for all forms of piano action, whether horizontal or vertical.

It is obvious from what has been said, therefore, that the piano action may conveniently be considered as divided into the following main elements (1) the hammer, (2) the escapement, (3) the key and (4) the damper. From the beginning all piano actions have possessed the 1st, 3rd and 4th of these, and in almost all cases a more or less satisfactory mechanical solution of the 2d has been carried out. The method of arranging these elements now to be described was first successfully worked out by Erard in 1821 for the horizontal, and by Wornum in 1826 for the vertical, piano. Let us now consider how these various elements are co-ordinated. I shall begin with the grand piano.

The Grand Action. Erard's principle is to-day universal in grand piano making, but the particular form in which it is generally carried out today was developed by Herz from Erard.[1] The illustration given herewith (No. 19), shows a modern grand piano action manufactured by Messrs. Wessell, Nickel & Gross of New York. The parts, arrangement of parts and method of regulation are quite typical of the very best American practice.

The terminology may be considered as correct and as following the practice of the best American action makers.

Operation of Grand Action. The student should now follow the argument by means of a working model, or by the simple process of removing the action from a grand piano and studying its motions. Pressing slowly the key of the action we observe that the rise of the rear end thereof affects the capstan (7) which lifts the wippen (11) through contact with the wippen knuckle (8). On this wippen are pivoted the repetition lever (19) and the jack (sometimes called "fly") (13). By lifting the hammer shank (27) up and away from its cushion (24) it will be seen that the

1 Cf. "Theory and Practice of Pianoforte Building," p. 96 *et seq.*, *Encyclopedia Britannica* article "Pianoforte," 9th, 10th and 11th editions, and "History of the American Pianoforte," by D. Spillane.

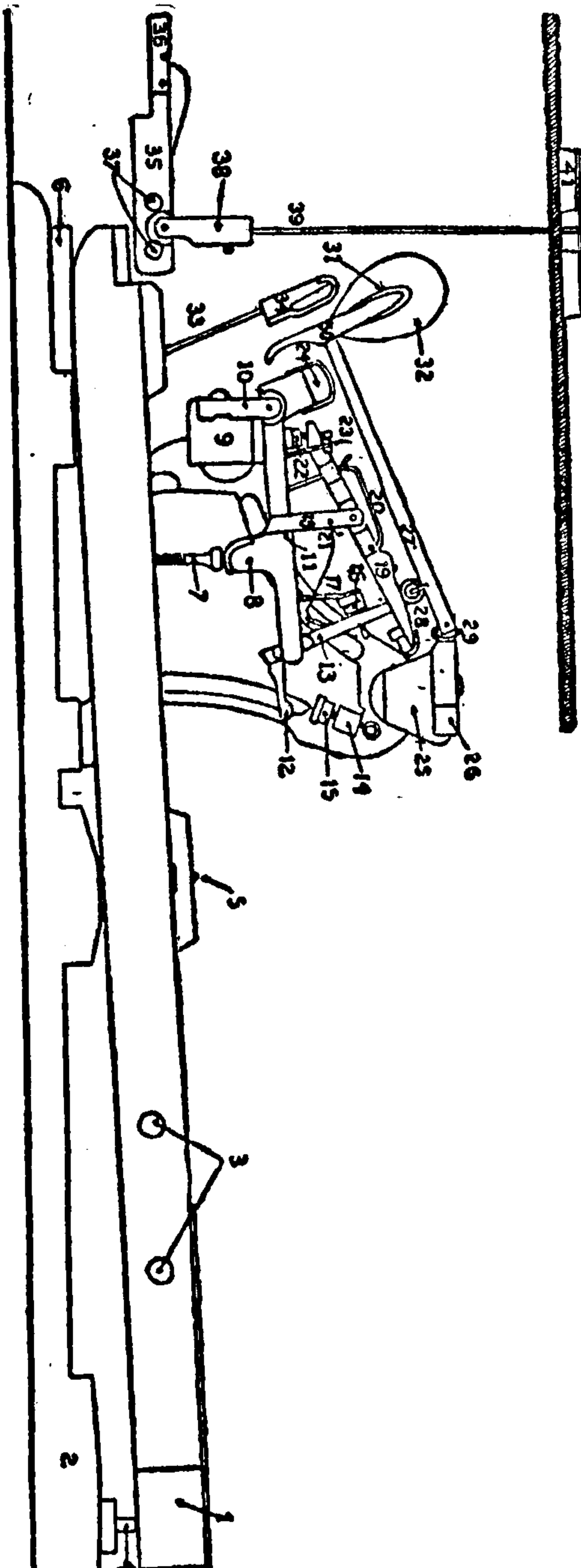


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FIGURE 19.

top of 13 works in a groove in 19. Moreover, the upper surface of 19 bears against the hammer knuckle (28) the weight of which and of the hammer, depresses 19 until 13 also is in contact with 28. When, however, the key is depressed it will be noted that the lifting is first done by 19 and that 13 comes in to play only after 19 has begun to lift the hammer. As the key is further depressed 13 lifts on the hammer and pushes it up to the string until tripped by its knuckle (12) coming in contact with the regulating button (15). The momentum of the hammer carries it up the rest of the way to the string, whence it immediately rebounds and is caught by the back check (33 and 34) which holds it until the key is released, when the hammer is again supported by 19, which holds the hammer up while 13 slips back under 28. The function of 19 then is seen to be that of assisting repetition, for by using it, the hammer may be again and again operated through the jack (13) without the finger entirely quitting the key. As may be seen by practical test on the action, so long as 19 holds up the hammer by means of the expansive strength of 20, just enough to enable 13 to slip back into place (which last operation is performed very quickly through the agency of 21), the stroke may be repeated; and therefore it is plain that the key need only be lifted enough to afford the finger a secure stroke. Really, then, 19 is the repetition lever in fact as well as in name and through its agency the escapement which otherwise would have to be affected by quitting the key and giving it time to rise entirely, is effectually performed.

Comparison with Square Action. The old square piano, still to be found once in awhile, presents in its action an interesting comparison with the above. Here will be seen the difference between single and double repetition. In the square action, the repetition lever is omitted and the jack can only find its way under the hammer butt safely, when the key is allowed to rise almost to its full height in front. Thus the finger action must be higher and the execution of rapid passages becomes difficult if not impossible.

The Back Check. There is, however, one other extremely important element which so far has only incidentally been mentioned. This element is common to all types of piano action, grand, square and upright alike, and is found in even the earliest successful pianos. I refer to the back check (33 and 34). The object of this is to catch and hold the hammer firmly on its rebound, thus assisting the recovery of 19 and 13. Even in pianos like the square, or older makes of grand, one always finds the back-check, whether the double-repetition device be present or not. Indeed, the inventor of the pianoforte action, Cristofori, to whom belongs premier honors as father of piano making, certainly mastered the necessity for the back-check in the course of his experiments, for he devised them, in almost modern shape, and built them into his last pianos. This may be seen by examining the Cristofori piano now standing in the Metropolitan Museum of Art, New York, the date of which is 1720. The back-check, then, is as old as the piano. This fact alone shows its essential value, for not otherwise would the necessity for something like it have been so quickly discerned. Cristofori, of course, was an uncommon genius, for in his last actions (1726 and later) he had also an under-lever, not unlike the repetition-lever of the modern grand piano, and very much like the under-lever of the "Old English Square Action" so-called; the object whereof is to steady the hammer and impart elasticity to the blow.

It will be observed that the back-check comes into action when the hammer, rebounding from the

cycle of motions may once more be set in motion, to be repeated as often as the key rises at the back enough to ease the back check from the hammer head.

Turning Points. Thus the grand action appears, in its sound producing parts, as comprising six centers and six radii, describing six arcs of turning. All piano actions may be similarly considered.

The Damper Action. The function of the damper (40) is to rest on the strings when the key is not in use and so prevent any vibration of the string, especially to prevent any sympathetic vibration which might be produced by the vibration of another string having partials in common. As will at once be observed, however, the damper is so positioned that when the key is in motion, *and has descended about one-third of its total dip,* the damper lever (35) begins to lift and with it also the damper head, so that by the time the hammer is about to make its stroke, the damper is well clear of the string. Upon the return of the key to its position of rest, the damper is allowed to fall back on the string, being pressed down thereupon by means of the spring in the damper lever.

Some European actions are to be found with dampers which normally press up against the under side of the strings by means of springs and are drawn down when the key is pressed. Such are the Erard, which retains the original action invented by Sebastian Erard in 1821, and the Broadwood of London, the latter being the oldest of existing makes.

Damper pedal. The damper action can be entirely raised from the strings, independent of the operation of the piano action, by means of the damper rod (not shown in illustration), which runs underneath the line of damper levers and is controlled by the right hand pedal of the piano through suitable trapwork usually placed under the key-bed.

General Construction Practice. The piano action in all forms is a wooden machine. Numerous attempts to devise a satisfactory action of metal have so far been uniformly failures, largely because the peculiar requirements of lightness, independence of lubricants and low frictional resistance seem to present insuperable difficulties. Although, therefore, the stickiness, dampness and liability to warping which naturally characterise wooden machinery of any sort render the piano action somewhat unreliable and distinctly trouble-some at times, it is not likely that much change will be made in the future, unless indeed some entirely new principle is discovered. On the whole, however, the wooden piano action, especially in its grand piano form, is a wonderfully efficient piece of machinery.

Being in effect a series of centers, with radii therefrom moving through arcs of circles, the piano action requires numerous pivotal points. These are now universally provided by means of flanges carrying brass center-pins, working in bushed holes, on which the levers turn. These flanges have been always of wood hitherto but for the last fifteen years there has been a constant and steady drift towards brass or other metal forms; and there is no doubt that the piano of the future will use such centers altogether; if only because they are more rigid, less likely to loosen at the bushings and more easily adjusted.

The woods used in the piano action have been briefly mentioned already [1] and here it may principally be said that the practice of the best makers has not noticeably varied in a good many years. Hard woods such as maple, beech, and sometimes

[1] Cf. Chapter VI.

the springs, which are always made of brass, but which, in grand pianos especially, seem to collapse and lose their "life" very soon under modern conditions. It would probably be a good thing if experiments looking to the substitution of steel springs were made; but the trade is conservative here, as everywhere. Capstan screws are also of brass always, but the remaining hardware is either cast-iron (action frames, screws, etc.), or steel (damper rods, etc.).

Detail Variations. Older grand pianos are often found (if made prior to about 1890) to have wooden rockers with short extension rods of wood, in place of the capstan screw. The method is not admirable, mainly because it renders the action less accessible.

Wooden action frames were also common in the old days, and wooden action rails are still almost universally used, although modern makers are beginning to see the advantage of at least supporting these rails by metal bars.

The construction of the repetition lever and of the wippen in general is subject to considerable variation of practice. Some makers (Steinway, Schwander) use a single spring, with double or single bearing. Sometimes the travel of the jack is limited by a metal spoon as shown in Figure 19 (Wessell, Nickel & Gross), and sometimes by a wooden post (Schwander), whilst in some actions (Steinway), no adjustable means are considered necessary. The greater number of modern grand piano actions are provided with tensioning screws whereby the strength of the wippen springs may be adjusted more surely than would be possible by any method of bending. But older actions are usually without this adjustment.

Steinway grand pianos are distinguished by the use of an octagon head screw in place of a capstan screw, which necessitates the use of a special wrench for turning them. The same makers use metal sheathing for their action rails, which are of special design.

The cushion on the wippen, above which the hammer is normally held, has given way in some grand actions to a fixed, independently supported hammer-rail on which the shanks rest as they do in an upright. Some of the Schwander actions are of this type. Strauch Brothers, also, have made some grand actions like this.

Soft Pedal. These last, however, are made specially for the purpose of substituting a lift of the hammer-line by the soft pedal for the usual shift of the key-board. The Isotonic soft pedal action by Kranich & Bach is of similar type.

Sostenuto Pedal. On most modern grand pianos, each damper-lever is provided with a tongue of felt projecting from it. In front of the line of tongues is a brass flanged rail which can be rotated by depressing the middle pedal (provided for that purpose). *After* a key or keys have been struck and their dampers raised, the pedal may be depressed *before* releasing the keys, and the flanged rail thus turns, catching the felt tongues and holding up the dampers. The keys may then be quitted. This device is useful in getting tone-color and adds to the tonal resources of the piano most markedly.[1]

Regulation of the Grand Action. The processes which together constitute the adjustment or "regulation" of the grand piano action are not complicated when studied systematically and in order. To describe them is by no means difficult; and indeed the only difficulty is to get enough practice to be able readily and rapidly to perform the various processes. In order to simplify as much

[1] Many other small detail variations may be found amongst the work of individual makers, but for general remarks along these lines see Chapter X.

cords the key a touch-depth (dip of the front end) of ⅜ inch. The bass end may be a little deeper, but on the whole this is not essential.

Touch-depth, however, the piano maker must consider in connection with rise of the rear lever of the key. Moreover, it naturally follows that as the front dip is to the rear rise, so is the length of the front lever (front-rail pin to balance-pin) to the length of the rear lever (balance-pin to capstan). If therefore the requirements of any action are such that special height of rise is required, the position of the balance-pin must be shifted accordingly. Usually, however, a rise of ¼ inch for the back is found sufficient. Taking this as a basis, the following simple calculation gives the other proportion:

*D*epth of front dip ⅜″.

Height of back rise ¼″.

Front Lever : Back Lever : : Front dip : Back Rise.

But, ⅜ : ¼ : : 3 : 2.

∴ Front Lever : Back Lever : : 3 : 2.

If, however, the proportions between dip and rise are altered, so also the length proportions between front and back lever are affected.

Length of Keys. In grand pianos of normal size the key lengths have finally been settled at about 15¾ inches from front rail pin to capstan. Short grands sometimes have to carry a smaller key, and in this case, to preserve the true front dip the proportionate lengths must still be as above, for if any change is made on the mistaken idea that some fixed length instead of a fixed proportion is to be followed, the entire key proportions will fall to the ground and the touch will undoubtedly be bad. By retaining the proper proportions as indicated above the short key will be effectual enough, although it must be remembered that the shorter the key the less the leverage for an equal touch depth.

Resistance. The practice of the best makers has finally settled the resistance or touch-weight at 2½ ounces approximately. Some variation between the extreme bass and treble ends is permissible and desirable. In fact it would be well to consider a resistance in the extreme bass of 2¾ ounces, graduated to 2½ ounces in the middle and to 2¼ ounces in the extreme treble. Changes in resistance may be made by drilling the body-wood of the keys and putting in small round pieces of lead where required. The piano maker should always carefully ascertain the weight required to depress each key when the action is in contact with it and having done this adjust accordingly by putting lead in the back of the keys to increase the resistance, or in front to lessen it.

Order of Regulating. Following the general factory practice we may consider the regulation of the grand piano action in the following order:[1]

1. Key frame, and keys. Key-shift and soft pedal.

2. Action.

3. Dampers, damper pedal and sostenuto pedal.

Keys and Key Frame. 1. Keys are removed from frame, which then is fitted with felt punchings for front and balance rails and strip of cloth for back-rail.

2. Keys are replaced and eased off, by being tested for clearance on front and balance rails. Each key should fall back when lifted, naturally and readily, but not loosely. Key-pliers are used for squeezing the bushings wider when needed. If keys are too loose, bushings may be squeezed together by punching with a wooden punch.

3. Key-frame is then placed under action (*same*

1 For the sake of clearness, it will be necessary to include certain processes actually classified as part of the preliminary Action-finishing.

put on pedal. Points of contact are black-leaded with powdered black-lead and burnished with heated steel bar. Spring which retracts key frame is also tested and adjusted if necessary.

Action. 5. Action being replaced on keys, hammers are adjusted so that length of stroke is not more than 2 inches from end to end. *(This is the action-finisher's work originally and regulator merely looks it over)*. Each hammer must then be adjusted to rest over its cushion about 5/32 inch. Capstans are adjusted accordingly and care taken to see that the hammers are level.

6. Jacks are then adjusted so that hammer trips up at about 5/32 inch from the string (*here practice varies but close regulation is desirable*). This is done by turning regulating button of jack.

7. Jack is regulated by turning button and screw on repetition lever so that jack normally rests in middle of groove in repetition lever. Usually a line on groove is marked to show right place.

8. Back-checks are regulated so that (1) they stand even and straight in line, (2) catch the hammers firmly without any slippage even on hard blows and (3) catch hammers when same have descended on rebound about 1/8 inch from the

strings. Use only proper bending iron or bending pliers for this work.

9. Repetition Lever is regulated; (1) spring is made strong enough to cause the hammer to dance a little and lift slightly when back-check is released. Most modern actions have screw tension adjustment, but otherwise tension may be changed by bending wires with hook; (2) rear of lever is set low enough to permit plenty of space between it and its travel-limiting hook, so that the jack may rest about 1/64″ below the level of the grooved end. This is usually done by means of regulating button (Figure 19); (3) height of rise of repetition lever under hammer-knuckle is regulated by Repetition Lever Regulating Screw (No. 29 same illustration), so that rise of Lever is stopped when hammer is still about 5/32 inch from the string, or (which is nearly the same in practice), a little before the jacks trip off; just enough before to give the jacks about 1/8 inch lift by themselves before tripping.

After-Touch. 10. Action and keys being in piano, keys are tested for evenness of dip. This is best done by means of wooden block of proper depth whereby each key may be tested from extreme bass up, by placing block on top of key and then depressing. If block sticks up too high take out punchings underneath front; if block sinks below level of key-top put more punchings underneath. Paper punchings are used for this work.

11. Testing for after-touch is then done. After-touch is the slight lifting of hammers which should take place when keys are gently released. If properly regulated, the release of the key immediately releases back-check and repetition lever lifts hammer slightly. To make after-touch right, put enough punchings under each key to make sure that hammers will not release from back checks except under very hard stroke; and then take out from this about $1/32$ inch punching depth. This will leave the necessary after-touch.[1]

Dampers and pedal work. 12. *D*ampers must lie square on strings and their wires work freely in bushings.

13. Each damper lever must be regulated so that the line of dampers, when lifted by the sustaining pedal, lifts all together evenly and looking like one piece.

14. *D*amper wires must be regulated so that lift

[1] It is often necessary and always better, to regulate the black keys separately and with the white keys removed.

means guiltless of ignorance in this respect, and that the real meaning and inner refinement of the upright action are almost as much a closed book to many of them as anything else one could mention. Crude and rule-of-thumb methods of regulating and repairing, handed down by tradition and practiced by men themselves unable to appreciate the piano from the performer's standpoint, are not calculated to improve either the durability of the piano or the reputation of the tuning profession. It is therefore without any further apology that I devote space to an analysis of the upright movement as painstaking as that which we have just finished.

Figure 20 shows the modern upright action, to which is appended a complete terminology as follows.

The illustration is of an action by Wessell, Nickel & Gross of New York.

Distinctive Features of Upright Action. The upright piano action is in two parts, separated from each other and only in mechanical contact; namely the keyboard and the action proper. These two can therefore be handled separately in a convenient manner.

The hammer does not fall back by gravity, and so must be assisted by the provision of an entirely new element, the bridal-tape (No. 20), as well as by the hammer spring (No. 36).

The hammer-line rests against a hammer-rail and the soft-pedal operates by swinging this rail to bring the hammers nearer to the strings. This creates lost motion between capstan and abstract, which in some actions is taken up by special devices.

There is no special repetition lever.

Operation of Upright Action. The key being depressed at its front end, the rear end rises, lifting the abstract (8) and the wippen (13). The rise of the wippen lifts the jack (17) which swings the hammer butt (25) carrying the hammer, until tripped at its knuckle by the button (22). Tripping of the jack throws it out of contact with the hammer, which moves forward to the string by its own momentum, and rebounds, assisted by the spring, till it is caught and held by the back check (19) working against the back-stop (24). When the key is released, the hammer is pulled back by the tape, which also assists in the retraction of the jack. This latter important part of the process is further assisted by the peculiar shape of the leather-covered hammer-knuckle against which the

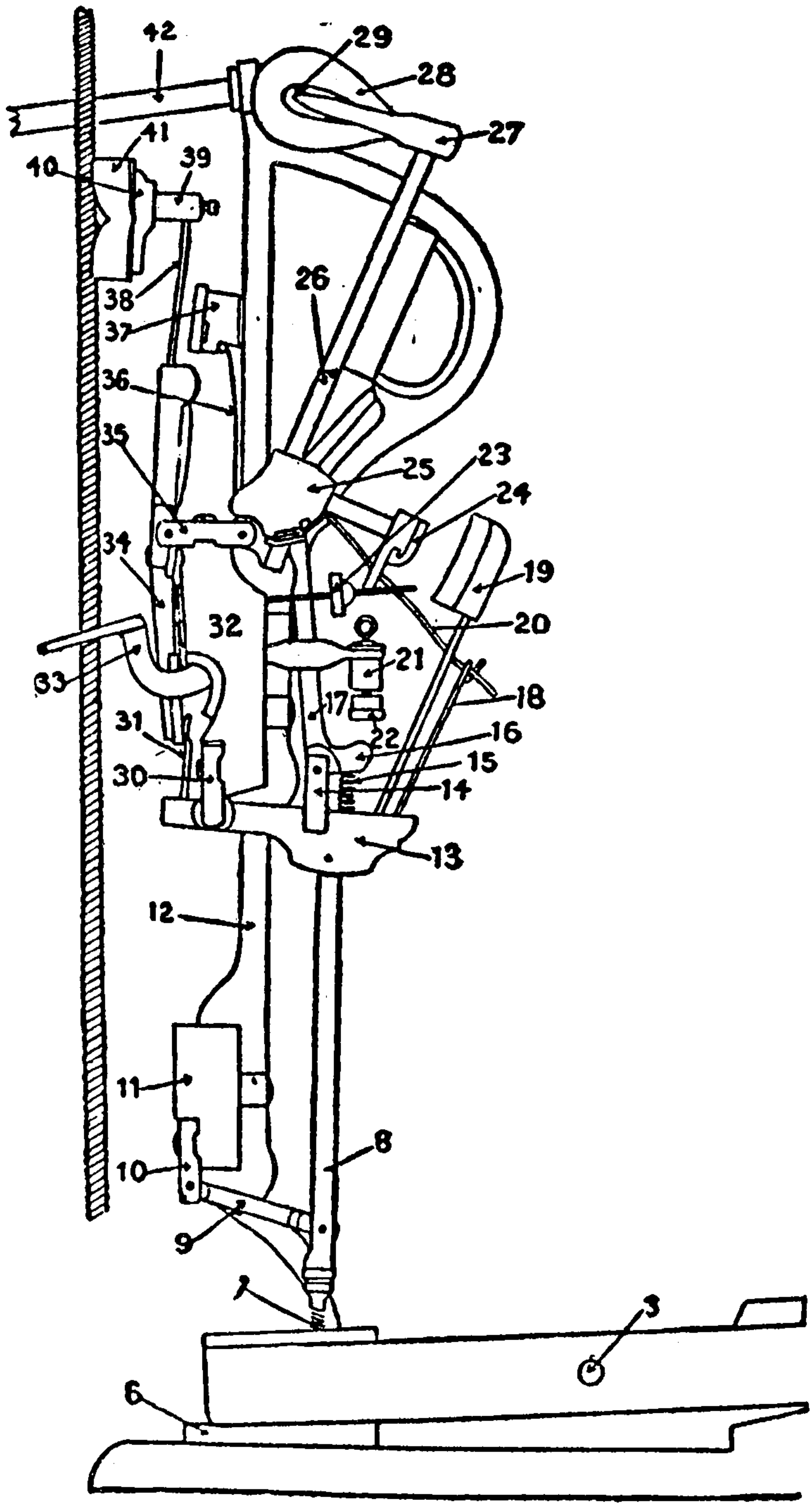
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FIGURE 20.

jack bears. When the key has already risen enough to bring the parts here described into play and start them on their arcs of turning, the spoon (31) presses against the damper lever (34) and the damper is pushed away from the spring. When the key is released, the damper is retracted with it till it against presses against, and damps, the string.

The action of the upright is somewhat simpler than that of the grand and the absence of a repetition lever is felt in the higher finger action and less delicate repetition. Nevertheless, if properly regulated, this action is efficient and rapid.

Comparison of the Upright with the Grand Action. The characteristic feature of the upright action is the bridle tape. The value of this tape lies mainly in the slight extra pull it manages to impart to the hammer butt when the hammer rebounds from the string, and after the back check has caught the hammer and been released by the release of the key. The tape would not have any special value but for the fact that the hammer, having been caught by the back check, naturally would hang a little on the release thereof, if it did not receive the gentle pull caused by the fall of the wippen with which the bridle tape connects it. The tape is, in fact, to the upright action what the repetition lever is to the grand. Until these two features had been devised and applied to their corresponding actions, the piano was an extremely imperfect instrument. The modern upright piano owes its present touch effect to the tape just as the touch delicacy of the grand is due to the repetition lever. Of course the grand action is the more delicate and responsive of the two, for it possesses the double repetition. This the upright cannot have, not to mention the fact that the fall of the hammer through gravity is of course far more effective than its retraction by springs. The upright action blocks more easily than does the grand, and finger movement must be higher to secure repetition.

Detail Variations. The metal flange is coming into its own even more rapidly on the upright action than on the grand. The first step in this direction was taken some years ago when Wessell, Nickel & Gross brought out the continuous brass plate with flanges, carrying each section of hammers on one plate. This did not prove to be the required solution, but the individual brass flange has since come forward and appears to be perfectly satisfactory. Certainly it does make the action more rigid and durable.

Metal rails or metal reinforcements to wooden rails are also coming into use and these are likewise an admirable improvement.

Some actions (Schwander) are provided with an extra spring in the jack, called a repetition spring. The same makers have eliminated the ordinary spring rail and in place of it have a separate support for each spring in the back of the hammer butt, fastened to a loop cord secured in the flange.

Lost motion attachments are common. These consist of a mechanical movement whereby the rise of the hammer-rail, on the depression of the soft pedal, causes a proportionate lengthening of the abstract, to fill up the gap which would otherwise be left between capstan and abstract.

Many attempts have been made at various times to eliminate the tape and provide for reliable repetition by other methods. The ideas of Conover Brothers, of Luigi Battallia and of many others might be mentioned, but modern practice in this respect chiefly centers about the "Master-touch" action of Staib-Abendschein and the Ammon "non-blockable" action of Christman. One principal objection to the tape is its liability to

plicable to the upright, and I shall therefore content myself with referring the reader to them, suggesting also that he study the various representative actions he meets with, for the purpose of discovering at first hand the practical facts of material and constructional usage as displayed by manufacturers. In this case, as in all others, practical first hand knowledge is priceless.

Regulation of Upright Action. Certain parts of the work of regulation are identical in method with what we have already learned concerning the similar processes in the grand action, but the differences in design between the two bring about such differences in parts and functions of parts that a separate description is necessary everywhere save in one or two instances; as will now be seen.

1. *Keys.* The preliminary work of felting, easing, leveling and spacing keys is done just as before described in the sections on the grand action. This work, in the present case, may be done without removing the action from the keys, so that it is unnecessary to put lead pieces at the backs of the keys to hold them up.

2. *Hammer-blow.* This is regulated to be about $1\frac{9}{10}$ inches. Regulation is made by putting felt

cushion between hammer-rail and action brackets.

3. *Lost Motion.* Lost motion between capstans and abstracts is taken up. Correct adjustment is indicated when the hammers lie freely on the hammer rail, neither forced above it nor with a gap in the action below them. As long as the back-checks move without moving hammers, there is lost motion; but it is advisable to leave a little, a very little, play, so that the jack is not hard up against the hammer knuckle.

4. *Back-checks.* Back-checks are straightened by means of the back-check bender or a pair of bending pliers, so that each check lies squarely in front of its corresponding stop.

5. Back-checks are lined up so that each check catches back-stop when hammer has descended about one-third of its total drop on rebound.

6. *Let-Off.* Jacks are adjusted for the trip of the hammers, which is done by turning regulating screws, using a regulating screw driver. Hammers should trip at a distance of from ½ inch (bass end) to ⅛ inch (treble end) from the strings.

7. *Bridle-Tapes.* Bridle-Tapes are adjusted to lift wippens evenly and all together. This is tested by hammer rail up and down, so that bridle

tapes lift and drop accordingly. Adjustment is made on bridle-wires.

8. Bridle-wires are adjusted so that they do not knock against back-check wires and lie straight and square.

9. *Dampers.* Dampers are adjusted so that they lie square against strings.

10. Rise of dampers is adjusted by moving damper-rod back and forth, so that it may be seen whether all dampers begin to move together. Adjustment is made by bending spoons. Dampers should lift not more than about ¼ inch from the strings and their movement should begin when key is about one-third of the way down.

11. *Sustaining Pedal.* The sustaining pedal action is adjusted to lift the damper-rod promptly. Adjustment is made on the trap-work at the bottom of the piano or between top of pedal rod and damper rod.

12. *Soft Pedal.* Adjustment is made at hammer-rail.

13. *Middle Pedal.* See *supra* in reference to grand actions.

14. *Touch.* All instructions regarding laying of touch in the grand action apply here to the upright.

Spoon bending iron
Parallel pliers
Capstan screw iron
Hexagonal wrench for Steinway actions.

Professional regulators, who operate in piano factories, use, of course, a much wider selection of tools, often including many devised by their own ingenuity. But the traveling tuner cannot expect to carry an arsenal of tools with him, nor indeed to burden himself with one single not actually indispensable piece. Yet the selection suggested above while it may at first seem formidable in quantity, really represents an irreducible minimum, below which the judicious worker cannot and will not, go.

Chapter IX.

THE HAMMER AND ITS RELATION TO TONE.

The hammer is the "characteristic" of the piano; its sign and symbol. It was exactly the invention of the hammer, and of a movement to connect it with the key, that made the harpsichord into the pianoforte. The object of the labors which led Cristofori to his epochal application of a principle until then regarded as practically unrealizable, was tonal gradation. He sought a keyed stringed instrument of music susceptible to dynamic control through variations in the stroke of the fingers upon its digitals. He was looking for something better than the harpsichord could give him; something better than the light thin tinkle which represents the ultimate achievement of any harpsichord, no matter how beautifully made. No increase in the vigor with which the harpsichord key is depressed will do more than gently pluck the string. Thin, rippling, tinkly, the tone of the harpsichord and of its kindred claviers could not always suffice for the full satisfaction of musical art. True, the harpsichord persisted for nearly a hundred years after Cristofori began his work in the little shop among the outbuildings of the Medici Palace at Florence; but on the day he produced his *martello* [1] and the crude movement which connected it with the key, not only was the piano born, but the harpsichord was doomed. Henceforward, percussion instead of plectral vibration was to be the characteristic of keyed stringed instruments.

The two hundred years that have elapsed have brought no change in principle, although they have seen much improvement in detail. The piano hammer remains precisely what it was. Changes in the materials of which it is made and improvements in the manner of its manufacture have been produced as part of a gradual general refinement of our conceptions of the piano and of its true place. These conceptions have brought about improvements in manufacture, which have been accompanied by parallel improvements in the machinery of manufacture. But the principle remains to-day as it was two hundred years ago.

Function of the Hammer. Fundamentally, the piano hammer consists of a rounded cushion of

[1] i.e., hammer.

shaped wooden blocks covered with hard leather and topped with a softer skin, like that of the elk. In the time of Beethoven the covering material was still leather, although an oval form had been developed. The felt covering which has long superseded all others was developed during the nineteenth century, principally through the work of manufacturers in the United States, where machines for covering the moldings were first successfully made and used. The present hammer consists of a wooden molding of approximately pointed shape over which is stretched a strip of hard felt known as the *under felt*. This is glued in place and over it is fastened in the same way a thicker strip of softer felt called the *top felt*. The two strips of felt are cut off large sheets, and glued on to the hammer moldings in one piece; the moldings themselves being also in one piece. Thus a whole set of hammer molding is turned out complete, and receives a strip of under felt nearly as wide as the whole set of hammers, which in turn receives a strip of top felt. The solid set is then taken out of the machines and sawed into separate hammers.

The sheets of felt are of different weights, running from 12 to 18 lbs. per sheet or even higher.

Hammers are known as 12-lb., 14-lb. or 18-lb. hammers according to the weight of the sheet from which their top felt is taken.

The sheets themselves are prepared in tapering form so that the thickness runs from greater to less in a constant gradation from one end to the other. In this way is preserved the gradation of thickness in the hammer-felt from bass to treble of the piano. Bass strings, of course, require the heavy hammers and treble strings the light ones.

Felt. The peculiarities of hammer construction must be considered definitely if we wish to become acquainted with the reasons for the sometimes peculiar behavior of hammers under usage. In the first place, it should be observed that felt is a very different thing from woven or spun fabric. Felt is the result of pressing together layers of wool in such a way that the fibres, which are serrated or jagged, fasten into each other and form a solid mass, which cannot be torn apart and which possesses in a high degree the qualities of flexibility and resiliency, together with strength and durability. At the same time however, it must be remembered that felt is a material which is really at its worst when under tension; yet hammer-felt is continually in tension after the hammer is manufactured. The felt sheet is stretched over a wooden molding, with the result that the whole outer surface of the sheet is subjected to considerable tensional strain, which tends constantly to pull the fibres apart; fibres which have in effect merely been pressed together in the process of felting and which therefore are susceptible of rupture under strain.

This peculiarity of the felt hammer is seen in sharp relief when a piano has been used any length of time. But even before this, even in the factory, the processes of tone regulation invariably expose this imperfection. In order to understand how this is so, however, we must see what that process is and how the condition of the felt affects tonal result.

Tonal Properties of the Hammer. An ideal piano tone-color can, of course, be expressed in terms of a definite wave-form. This form, we can safely assert, differs not in essentials in any pianos made anywhere. All piano makers of all nations are agreed, generally speaking, upon the kind of wire used, the points of contact, the employment of felt hammers and the general taste of the modern ear for piano tone; or rather for what we have come to accept as good tone for a

wire were on the whole softer and the tension lower, than are usual, the 9th and high partials would diminish in amplitude and consequently their influence on tone would be diminished.[1]

Now it is plain that the hammer must also enter into the complex as an influence of more or less power. Putting aside the question of contact points, which after all is a matter for the scale draftsman and not for the hammer-maker or the tuner, we are reduced to three considerations: (1) the hardness or softness of the underfelt; (2) the hardness or softness of the top-felt and (3) the size and shape of the hammer. Let us consider these.

Under felt. It is of course plain that the under felt must be relatively firm and hard, simply because the necessity exists of interposing an effective cushion between the hard wooden molding and the contact surface. It is equally clear that the function of the underfelt is, just as much, that of "backing up" the softer top felt.

Top felt. The function of the top felt is to inflict the blow on the string in such a way as to

[1] The published proceedings of the Chicago Conference of Piano Technicians for 1917 contain some interesting discussions of this point.

produce the necessary wave-form required. Now, it is plain that the softer the top felt may be, the less quickly will it rebound from the surface of the struck string. Now a soft top felt of course will be one in which the fibres will be relatively more detached on the top; a condition partly arising from the fact that the top felt is stretched at high tension over the under felt and molding. The cushion of soft fibres thus formed will tend to cling to the surface of the string a little longer than if it were perfectly smooth and hard. This clinging will have the effect of damping off at least some of the high partials which originate around the point of contact of the string. When it is understood that the hammer, even when new, presents a relatively blunt surface to the string, the above can easily be realized.

Soft and Hard Felt. It now becomes plain that:

1. The softer the top felt the less complex will be the wave form and the more mellow the tone quality, due to damping of high dissonant partials.

2. The more sharply pointed the contact surface, the smaller is the actual mass of felt presented to the string and the fewer are the upper partials around the contact point to be damped

by the contact. Hence, a pointed hammer, other things being equal, means a less mellow and more complex tone.

3. The greater the velocity of travel to the string, the more rapid will be the rebound, since action and reaction are equal and opposite. Therefore the harder the hammer-stroke the less mellow will the tone quality be, other things being equal.

4. For the above reason, also, a lighter hammer will rebound more quickly than a heavy hammer on a light hammer-stroke and the heavy hammer will rebound more quickly on a stroke powerful enough to move its weight freely and derive the velocity-advantage thereof.

The Voicing problem. The business of the voicer is to exert such influence as can be exerted by treatment of the hammer-felt, upon the tone-quality of the piano. Fundamentally, the tone-quality is settled long before the voicer sees the piano. The design of the scale, the general construction of the piano, the choice of striking points for the hammer; these and many other details have already determined the tonal quality before any treatment of the felt is considered. The sole business of the voicer then is to smooth

Smoothing the Surface. Now it is obvious that before any sort of judgment can be formed rightly regarding what may have to be done to a set of hammers in order to provide the best possible tonal result, the surface of the top felt must be made as smooth and as even as possible. This the voicer does by a process generally called "filing." A strip of cigar box wood is taken, about wide enough to cover the surface of a hammer when laid over it, with some space to spare, but not wide enough to interfere with the hammers on either side. This strip may be made of any suitable wood, but the kind spoken of is particularly convenient and easy to obtain. The strip is made about seven inches long. Several of these strips are obtained and covered with sandpaper by the simple expedient of cutting a strip of the paper to the same width and twice the length and then gluing it over the one edge and down both sides. The loose ends are trimmed off where the hand grasps the instrument. Some of the strips are covered with No. 2, some with No. 1 and some with No. 0, sandpaper.

Filing. The "sandpaper file," as it is called, is used for the purpose of rubbing away the rough uneven particles and fibres of the felt so as to produce an uniform surface. The technic of the operation may easily be acquired, but practice and patience are requisites to success. The action is laid on its back away from the piano, if this be an upright, or is taken out with its keys if it be that of a grand, and placed on a table or bench. The operator sits with the backs of the hammers nearest to him. Taking one of the hammers between his thumb and first finger he raises it above the line of the others and grasping the file in the other hand so as to leave as much of the sandpaper available as he conveniently can, he draws the file along the striking surface of the felt, beginning at the bottom of the under side of the hammer and drawing the file in a series of light strokes towards the top or crown where contact is made with the string, *leaving the actual crown untouched.* In this manner he smooths out the surface, rubbing away the rough outside crust of the felt and drawing this latter up to a curl at the crown. By so doing the position of the crown is indicated and any flattening of it avoided. Then the hammer is attacked in the same way on its other side and the smoothing out again terminated at the crown, so that now the hammer looks like a bald head with a little tuft of hair at the very top; a sort of Mohammedan topknot. In doing this apparently quite simple work, however, it is well to remember that (1) the strokes must be made with the file absolutely square on the surface of the felt, or else the result will be a crooked surface. (2) The file must be drawn just with enough pressure to take off the rough outer crust or skin but not hard enough to make dents in the surface or disturb the shape. Careful practice is therefore necessary, as well as a good deal of patience. Moreover, the high treble hammers which have so little felt on them must be very carefully treated, or the felt may be all filed away, leaving a bare spot showing the wood underneath. This first smoothing is done with the No. 2 paper.

First Needling. The voicer now turns to the needles. Having given the surface of the hammer a preliminary smoothing out, he must attempt to produce an uniform texture in the interior. The object of so doing is to furnish a cushion for the immediate contact with the string, which shall be relatively resilient and uniformly yielding, against the harder under felt and still harder molding. This upper cushion however, must not be mushy at the crown or actual place of contact, nor must its surface be broken up and its fibres disrupted by unscientific jabbing with needles. On the contrary, the object is to work the in-

It is necessary for the voicer to estimate from time to time the condition of the felt and the progress of his work. At the beginning, before he has filed the hammers, he will of course have tested the general condition of the tone and will also have estimated the hardness of the felt. His work must continue until the interior of each hammer is in an uniformly resilient condition, without uneven lumps anywhere, but especially without any picking up of the surface or tearing of the fibres, and without touching either the crown or the under felt.

"Picking Up." The abominable practice of "picking up" the felt by digging with the needles as if one were digging potatoes out of the crown of the hammer, cannot be too strongly condemned. It does the very thing which should not be done; weakens the already tightly stretched sheet of felt by breaking the fibres and crushing the structure at its surface. The consequence is that the entire crown is soon broken up, its indispensable firmness destroyed and contact made mushy and ineffective, whilst the interior of the hammer is left virtually in its original state. Thus the purpose of voicing is entirely missed. The needle-work should be done as indicated and in no other way;

continuing until it appears by the "feel" of the felt that each hammer is well worked inside.

Trimming the Crown. The voicer now trims off the felt tuft or "top-knot" on the crown of each hammer with his sandpaper file and replaces the action in the piano to test the tone. It will then be found, probably, that the quality is more or less mellow, but that there is much unevenness, some hammers being harder than others. The voicer therefore tests the tone quality by first running over the piano, a few hammers at a time, with a soft touch and then in the same way with a hard touch. The tone quality ought to be the same in both cases. Also the tone throughout should be of even mellowness. To remedy the unevenness the voicer uses his needles as before on the faulty hammers, again avoiding the crown, until the tone quality is evened up on a moderate touch. He then tries each hammer on a hard stroke and if the tone quality hardens when the stroke of the key is very strong, the voicer takes a needle holder containing two ¾ inch fine needles and with these takes a few "deep stitches," as they are called, down into the top felt; avoiding the under felt and the crown. This will remedy the trouble, which was due to the interior not having been worked sufficiently.

Second Smoothing. The hammers are now smoothed again, with finer paper on the file, and any specially hard hammers that may have been noted are needle-worked until they are in good shape. The action is then replaced in the piano.

The "Dead" Tone. If the work has now been done rightly, the tone will be mellow and even on all kinds of touch, but with a sort of "deadness." One feels that it needs to be livened up; and this can be accomplished in the following manner:

Ironing. The action being again taken out, each hammer is carefully ironed with a hot iron. This tool is best made from an old 1½ inch chisel, of which the blade has been cut off below the edge. Let this be heated until a drop of water touched to it evaporates and then let each hammer be well pressed with this on both sides. One side is held with the hand whilst the iron is pressed into the other side, working so as to direct the pressure upwards towards the crown and bring the felt in the same direction. This is done on both sides of each hammer until the felt is well scorched and blackened.

The file is then applied again and the scorched

which will remedy the conditions. It is his duty to watch carefully all points of the design and construction which have relation to tone, and to suggest such improvements as his own knowledge leads him to discern. These are counsels of perfection, but they are necessary nevertheless.

A fine ear for tone-quality may be acquired by patient study of the physics of piano construction and by constant practice in the art of voicing. No other possible road can be recommended or even suggested. The aim and end of voicing is to make the piano sing beautifully, and only constant work on the piano makes this idea possible of realization in one's mind; an indispensable preliminary to its realization in concrete form.

The Ideal. The ideal piano tone is that in which a wave form excluding the seventh and all partials above the eighth as far as possible shall be evoked uniformly under all conditions of touch. It is the object of the piano hammer to make this tone possible; and of the voicer to carry out the technical processes necessary to prepare the hammer for its tonal work.

The matter of repairing old hammers, and cognate matters relating to the care of the hammer in used pianos, are discussed in the next chapter.

The rules here laid down for the work of voicing are of course based on the practice of factories; and the tuner who studies this chapter is expected to understand that his practice must be modified in accordance with the condition in each case. Old pianos cannot always be treated exactly as described in this chapter, although every one of the rules and directions here given for each of the processes described and explained, is to be followed, at all times. This is important: to follow the entire process may sometimes be out of the question, but every time a needle or a file or an iron is used, the directions given above should be remembered; and, as far as possible, followed out.

Care of Tools. One point remains. In using his tools the voicer should be careful especially about keeping the sand-paper files always covered with fresh paper, and about renewing the needles whenever they become dull at the points. Worn sand-paper and blunt needles prevent good work and cause waste of both time and energy.

Chapter X.

REPAIR OF THE PIANO.

Definition. Piano repairing, for the purpose of the present chapter, is held to include all the work that the tuner is called on to do on upright or grand pianos after they have taken their places in the purchasers' homes. In chapters which have gone before I have said a good deal about the technical processes of piano construction and adjustment, but these remarks have been concerned with the piano in course of manufacture. The special subject of repair and adjustment of used pianos deserves and requires a special chapter.

Square Pianos. The square piano is obsolete, but I have included at the end of this chapter some brief remarks on certain peculiarities of these old instruments.

Classification of the Subject. In order to make the subject more intelligible, I have adopted the following classification, marking out the subject in subdivisions and discussing the particular topic

a thin fluted brass tube, fitting over the tuning pin and driven with it into the wrest plank hole. A worn hole can be filled up in this way and a complete new surface provided for the old pin to work in. A pin thus treated will tune perfectly, stand in tune for a long time and eliminate all driving of the pin or other make-shifts.

2. *"Jumping" pins.* These may also be remedied by the use of the above mentioned device, or else by the expedient of removing the defective pin or pins, and blowing a little powdered chalk into the wrest-plank hole. The cause is usually grease or oil which has soaked into the wrest-plank through some carelessness on the tuner's part; thus producing one of the most annoying of piano troubles. Pins that jump cannot be manipulated in fine tuning, and much the same is true of pins that are too tight.

3. *Broken Pins.* The best way to handle a pin which has been broken off at the eye is with the tuning pin extractor, which is a short steel head like that of a tuning hammer, but provided with a reversed thread tapped in it. The extractor is placed on a handle of its own or can be had to fit on to a tuning or T-hammer. It is worked by screwing it down reverse way on to the broken

stump of the tuning pin. This cuts a thread on the stump and grips it tightly enough to enable the operator to pull it out of the wrest-plank, which is done by gently turning it in the plank hole until it is loosened enough. One must be careful not to get the head so firmly fastened into the stump of the pin that it cannot be unscrewed therefrom. It is best, in fact, to turn back on the pins a little way after starting the thread and to keep on doing this from time to time whilst the thread is being cut.

4. *Wrest plank holes split.* The holes in the wrest plank in old pianos sometimes are split across the mouth and it is occasionally necessary to block them up and re-bore them. In doing this, maple dowels should be used for the plugs, which are driven in with glue. The hole is first reamed out somewhat and a dowel driven in to fit tightly, so that when the hole is again bored for re-insertion of the pin there will be enough dowel left to act as a bushing all around.

5. *Wrest plank split.* It is better not to touch wrest planks that are split unless one is very sure of what one is doing. Old pianos with open wrest planks sometimes give way at the gluing between the wrest plank and the back posts; that is to say

along a line parallel with the hammers from bass to treble, so that the entire wrest plank pulls away from the back, carrying the strings and tuning pins forward with it. If such a case is met with the tuner may sometime be able to repair the plank as follows: Loosen up all strings, screw wrest plank back into position by hand screws, and leave same tightened in place. Remove all lag-screws. Bore out lag-screw holes right through wrest plank and out at other side of back. Procure threaded square-head bolts of suitable diameter to fill lag-screw holes and long enough to stick out at other side, together with washers for head and tail of same and nuts to tighten at back. Have at least five such bolts and if there are not enough lag-screw holes for this purpose, bore out extra holes through plate and wrest-plank if necessary to afford further protection. Loosen hand-screws. Pour glue (hot) along and into the crack between back of plank and back post of piano. Screw up hand-screws again. Insert bolts with washers on at heads, driving them well through till threaded ends emerge at back. Put on washers and nuts at back and turn same down as far as they will go. Tighten hand-screws further to take up slack when bolts are turned in. Leave hand-screws on

times possible to tune one string against the other, as it were, so as to play off one set of false beats against another. In bad cases, remove the old wire and string.

9. *Bass strings "Dead."* Bass strings sometimes go "dead," losing all their beauty of tone and emitting a dull hollow sound. Try loosening string, putting hook in hitch-pin eye, twisting string a few times and replacing as twisted. This will often take up a loosening in the covering wire that is a frequent cause of dead tone. In bad cases, remove and replace with new strings.

10. *Bass strings rattle.* This is usually through loosening of the covering wire or of the pins on sound-board bridge. (See page 252.) Remedy accordingly.

11. *Treble strings rattle.* Causes are as above. Sometimes pressure bar is loose, but be wary of tightening too much.

12. *Obtaining new bass strings.* Bass strings must be made to order. In getting new ones, send along old strings, whether one, a few, or a whole set.

13. *Defects of iron plate.* Apart from screwing down the bolts on an unstrung piano the tuner

can do virtually nothing with defective plates save send them to the factory. Broken plates can be re-welded by the oxy-acetylene process.

Sound-Board and Bridges. 14. *Sound-board split.* Small splits are not dangerous and do not affect tone unless they cause the board to loosen at the edges. Splits are caused by alternate compression and expansion of the wood due to weather and cognate conditions. If it is necessary to repair a split, open same up with sharp knife till it is even from end to end, and insert a "shim" or short strip of sound-board lumber, which may be obtained in quantities from any factory, using hot glue and driving well in. Shims are triangular in cross section and are driven in sharp edge down. When dry, they must be trimmed off and smoothed down.

15. *Ribs loose.* Sound-board ribs are glued in place. If they spring out of place they must be screwed down by drilling small hole into rib from front of sound-board and then driving screw from same side into rib, through the board, with a bridge button at head of screw to take up uneven thrust. Glue brushed over surface of board where rib has sprung also helps screw to hold.

16. *Sound-board rattles.* Usually in grand pianos the trouble is that something has dropped onto the board. Get a long strip of steel like a corset steel, fasten little pad of cloth on one end and explore surface of sound-board therewith, thus removing dust and grit, pins, pennies, etc. In the upright piano, the fault is usually looseness of bridges, or splits. Of course these same conditions occur in the grand piano too.

17. *Bridges rattle.* Strings rattle on bridges when pins are loose. Drive pins in further and file over if necessary. In bad cases put in longer pins. If bridge is split, saw out split section to depth of bottom of pins, and send to factory. New part will be returned bored and pinned, ready to be put back in place, which should be done with glue and screws. Bridges also rattle when buttons behind are loose or when they have sprung from surface of sound-board. Remedies are obvious.

18. *Bass bridge loose.* Bass bridges sometimes come away from the sound-board, especially when they are of the extension variety. If extension bass bridge splits in half, remove bass strings and re-fasten with glue and screws.

Keys stick when depressed.	Ease front rail mortise with key-pliers.
Keys stick on balance rail.	Ease balance rail mortise.
Keys rattle and shake.	Re-bush mortises, using bushing cloth and wooden plug to hold cloth whilst drying. New key top buttons can be had in sets for old keys.
Keys sunk in middle.	Replace worn punchings on balance rail and re-level.[1] If necessary, build up key-frame with card-board under balance rail.
Keys rub in front.	Re-space and straighten.
Keys sink. Key Level uneven. Lost motion. Back checks block. Hammers block. Repetition bad.	See Chapter VIII (regulating).[2]
Dampers buzz on strings.	Straighten on strings.
Dampers don't rise.	Bend damper spoons.
Bass dampers catch.	Straighten dampers and re-bend wires.
Jack action feeble.	Strengthen springs under jacks.

20. *Defects of grand action.* Nearly all the above remarks on the upright action apply also to the grand, but the following additional instructions are also useful.

Hammers out of line.	Re-space.
Hammers don't check.	Re-bend back checks.
Hammers re-bound too high.	Regulate repetition lever to trip a little lower.
Hammers strike loosely.	Contact roller under hammer butt is flattened. Re-leather.
Hammers squeak.	Contact roller worn bare. Springs in action worn through felt bushings. Rust on springs. Remedy accordingly.

[1] See pages 205 and 218.
[2] Pages 218–219.

Dampers stick.	Bushings in rail are swelled.
Dampers don't damp.	Straighten on strings, clean felt, regulate fall.
Keyboard rattles.	Key blocks not tight down. Or key-frame warped. In latter case, glue cardboard between frame and key-bed.

21. *Trap work in upright pianos.* Old style wooden trap work often shakes, rattles and suffers from lost motion. Use black-lead for squeaks between springs and wood, and soap for trap-pins. Oil pedal bearings when same are of metal and take up lost motion at adjusting points on trap work. See especially whether soft pedal rod shakes at top or rattles. This is a common defect. Use felt punchings for taking up lost motion where no screw adjustment exists. Vaseline on coiled springs stops squeaks.

22. *Trap Work on grand pianos.* The only difference is in the fact that the grand trap-work is placed in a separate lyre. Sometimes the pedal foot sticks in the lyre, or there is lost motion due to worn bushings. The trap levers are usually found under the key bed and in modern instruments a screw adjustment on the lifting rods permits the taking up of lost motion. Other difficulties can be remedied the same as for the upright.

23. *Varnish.*

Blue look on case.	Due to moisture and dust combined. Avoid polishes. Simply wash off case with soap and water and dry with chamois leather.
Bruises.	Fill in with melted sealing wax, if deep, then cover with film of melted shellac, which sand paper down, and touch up with French varnish. To polish same, rub with powdered pumice stone and pad, using water to moisten, finish with rotten stone and pad and then with hand moistened with rotten stone and water. Oil off as below ("Oiling off case").
Light scratches.	Rub down with powdered pumice stone and finish as above. Touch up with French varnish if necessary.
Deep scratches.	Fill with shellac and proceed as above.
Renovating old case.	Scrape off old varnish, then smooth case with sandpaper then with pumice stone rough. When surface is clean, re-varnish two coats rubbing varnish, two days apart, rub down rough with pumice stone and water, flow over with flowing varnish and then polish, as below.
Polishing varnished case.	After flowing coat has dried (5 days) rub down with pumice stone powder, water and felt pad till all parts are flat. Then run out scratches with rotten-stone, water and pad. Finish with hand till brightened up. Oil off as below.
Oiling off case.	Parts being cleaned of powder, etc., rub lightly with cheese-cloth on which has been poured some lemon oil. When this has been done well, wring out another cheese-cloth in alcohol and wipe off lemon oil. Alcohol must be almost dried off before using cloth.

Defects of sound-board and bridges.	Sound-board sags in middle sometimes enough to cause hammer rail to touch it. Pins in bridges loosen. Bridges split. Sound-board splits.
Defects of case.	Wrest-plank sometimes sinks so that it is necessary to pare off some of the under surface to enable hammer rail to have free space. Key bed often sinks in middle and lets down touch of keyboard. Remedy is to build up under key frame.
Defects of action. Hammers loose.	Tighten split flange, or if flange is fixed put in larger pin. But see that hammer moves freely.
Hammers don't strike squarely.	Re-space hammer butts.
Hammers twisted.	Bend stems over with alcohol lamp.
Hammers rattle.	Glue loose somewhere. Investigate and re-glue.
Hammers worn.	Get new hammers by removing old ones and sending them in as samples. Re-capping with leather is usually very poor policy.
Jacks sluggish.	Springs are usually weakened. Replace or strengthen.
Excessive lost motion in action.	Screw up jack rockers but leave enough play to ensure jack getting back into place under hammer.
Keys rattle.	See directions for uprights.
Dampers rattle.	Bushings of lifter wires are loose or worn.
Dampers stick.	Bushings swelled. Heat lifter wire and push in and out of bushing till same is expanded.
Dampers don't damp.	Probably damper levers don't co-act with lifter wires. Re-space.

Other defects can be understood and remedied by study of previous instructions on upright and grand pianos.

26. *The Old "English" Square Action.* The old English square action is still occasionally met with. In this the hammer is supported by an under-hammer which is raised by the key and the regulation for the escapement of the jack is on the key. All parts are usually very small and delicate and instead of pinned centers there are often hinges of parchment or vellum. Great care is necessary in handling these old actions, which are usually much sunk and out of line, but the tuner will find that individually to study each case is the only sound advice that can be given.

27. *Tools.* The importance of good tools cannot be overestimated. There is no greater mistake than to suppose that one can do good work with bad tools. Many special tools are manufactured for the use of piano makers and tuners, and all of them are useful. Regulating, especially, calls for many tools of special design, such as regulating screw drivers, spoon benders, key spacers, key pliers, wire benders and others of the same sort. Special conveniences are also to be found such as pocket glue pots, center pin carriers, wire carriers and similar articles. The tuner should take pride in having the best possible tools and in carrying them most conveniently and

accessibly. Some of the tool kits put up by various manufacturers, containing complete sets of tools for all kinds of outside work on pianos and player-pianos, are extremely attractive and practical. I know; for I have used them.

My own experience proves amply the value of some advice which was given me when I started out as a tuner: "Get the best tools, learn to use them skilfully and keep them in perfect condition. This alone may not make you successful, but without this respect for, and care of, your tools you will never get anywhere."

Nor can one afford to neglect the matter of appearance. The tuner does much of his work in the customer's house. He is largely judged by the appearance of his clothes, by his manner, and likewise by the workmanlike or unworkmanlike appearance of his tools. A neat case of bright, clean, fine-looking tools is an advertisement: it is also an aid to efficiency.

must anyhow know to-day about players, should study the subject systematically.[1]

Need of Instruction. It is no secret that the arrival and rapid progress of the player-piano have been most seriously disturbing to those members of the tuning profession whose views are already formed and their methods more or less settled; in short, to the older and more conservative tuners. It is safe to say that as late as the year 1896 very few tuners had ever given serious thought to the possibility of a mechanism for piano playing being developed at all; much less to the possibility of its becoming immensely important to the trade and a knowledge of it in some shape essential to success as a tuner. That this should ever happen would have been thought absurd; that it should happen within fifteen years would have been thought ludicrously impossible. Yet the impossible has become the possible, the "could-not-be" has become the Is. The player-piano is with us; most of us have been caught quite unprepared for it.

Scope of these chapters. In the circumstances, seeing that already nearly one-half of the pianos

[1] The book referred to is "The Player Piano Up-to-Date," published by Edward Lyman Bill, Inc., N. Y., 1914.

made in the United States are player-pianos and that the ordinary upright piano without player seems positively to be doomed, it is plain that one could not very well avoid writing some chapters on the player mechanism in a book like this. On the one hand, then, I have attempted to make sure that the information given here shall be always clear, accurate and intelligible; whilst on the other hand I have not failed to remember that the tuner whose interest in the player is confined to attaining such acquaintance with it as will enable him to make necessary small adjustments and trace the cause of apparent defects in its performance, will neither require nor desire a lengthy treatise. To be accurate and intelligible whilst being also very brief is not easy; but I hope that I have succeeded measurably well in carrying out this requirement.

In this and the two following chapters, then, I undertake to set forth briefly (1) the fundamental principles of pneumatic player mechanism (2) a general description of the modern player-piano in its pneumatic aspect and (3) such instructions as experience shows to be most useful in the adjustment and repair of defects. The treatment is such that the reader will have no difficulty in following everything set down here.

The Mechanism. The player mechanism, whether it be built right into the piano or placed in a cabinet detached therefrom, is self-contained and entirely independent of the piano. Usually to-day it is interiorly built, fitting into waste space within the case of the upright piano. It is also now fitted into grand pianos, but in its principal embodiment remains an addition to the ordinary upright, built within the case, but independent of and not interfering with the regular action, scale or sound-board. The player mechanism can be withdrawn from the piano case very readily and is in all respects separate from the musical instrument itself.

The function of the player mechanism is to render musical compositions by playing upon the piano action, either through the keys or directly upon the abstracts or wippens thereof.

The player mechanism runs on power furnished by bellows blown by the performer.

Various means for expression are provided, controlled either automatically or at the will of the performer, the objects of which are to permit, as required, variation of speed, use of damper lift, loud and soft stroke of hammers, and division of melody from accompaniment parts.

say that the air of the atmosphere exerts a pressure at its bottom (the surface of the earth), of about 14.75 pounds per square inch.

Expansion. Air is a gas and all matter in a gaseous state has the property of expanding continuously to fill any space in which it may find itself. This expansive property together with the weight of air is the foundation of the operation of all pneumatic machines.

The air normally fills at normal pressure all closed spaces capable of containing air. It is everywhere and always present at normal pressure, unnoticed and unconsidered, until by some artificial means it is either rarefied or condensed. Then work can be done by means of it. If a closed bag, which is normally filled with air according to the natural facts of the case, be shut off and closed so that no more air can get into it from the outside, and if then the bag be enlarged, without any more air being allowed to flow into it, the contained air will have to expand to fill up the enlarged space. In so expanding, the air is acted on like the rubber in a rubber band which is stretched. It becomes thinned out, so that any cubic inch of it now weighs less than a cubic inch of it weighed before it expanded. Hence the pres-

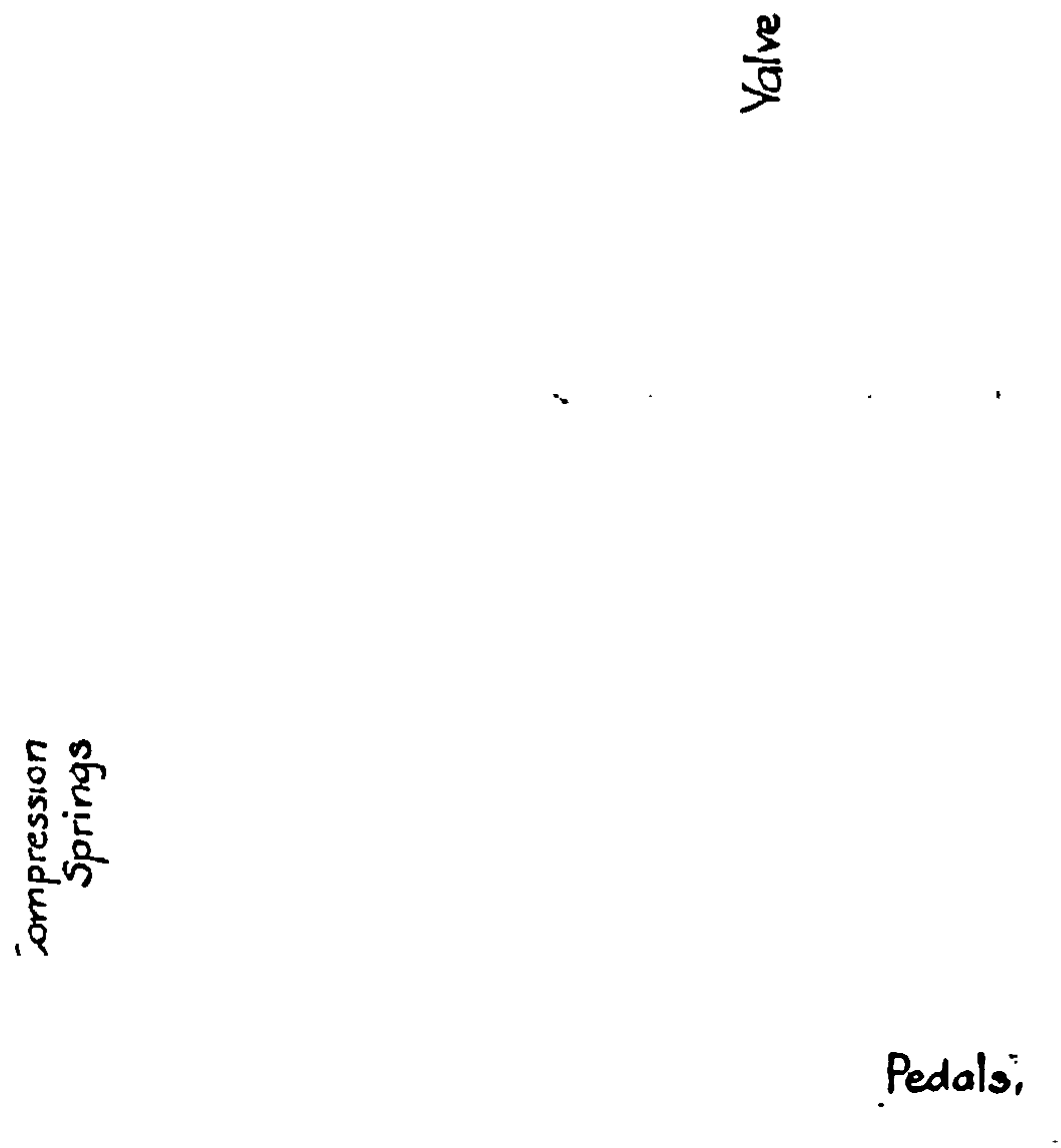

FIGURE 21.

Essential parts of player mechanism, pneumatic open; (not to scale)

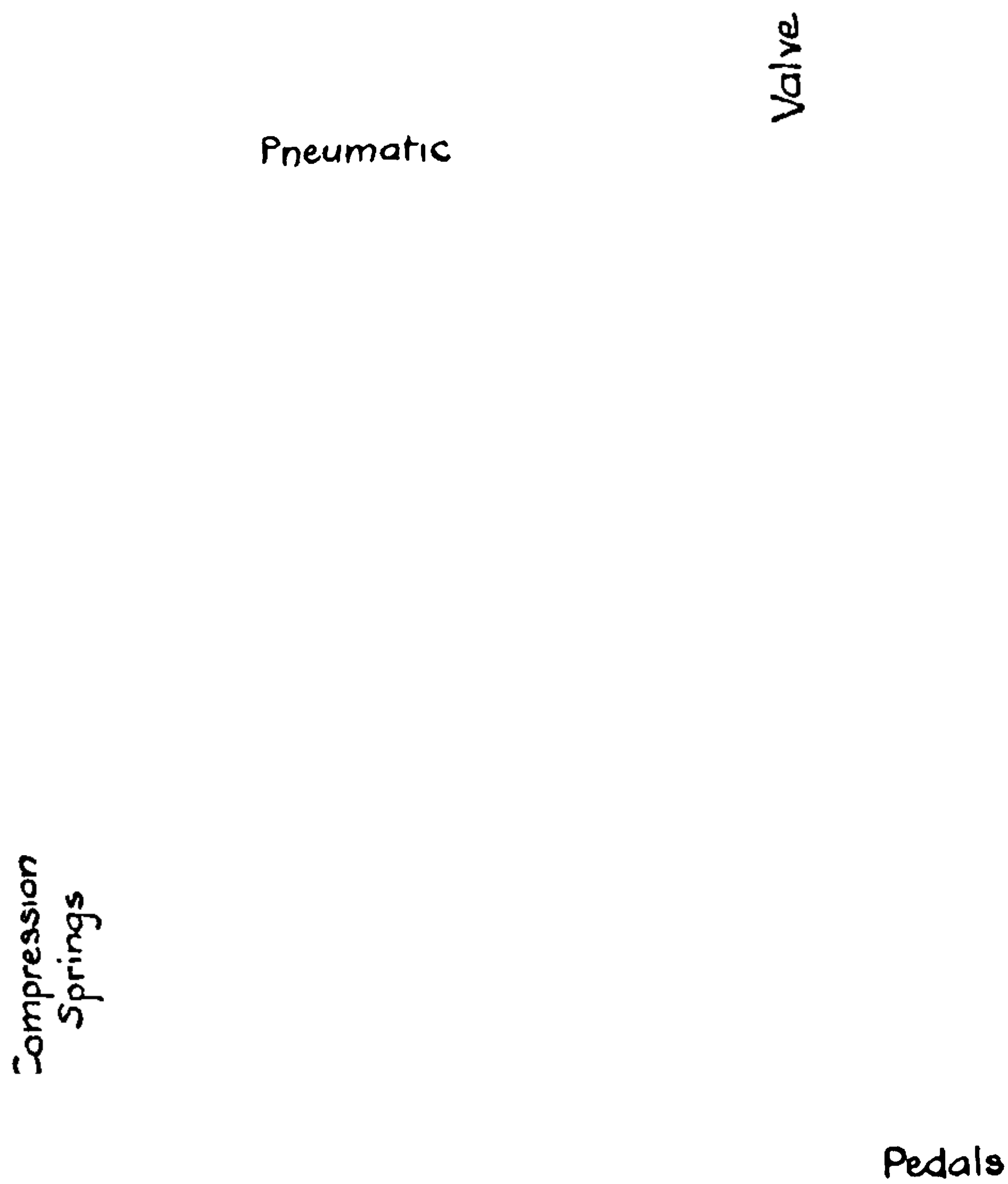

FIGURE 22.

Essential parts of player mechanism, pneumatic closed; (not to scale)

rest with, therefore, both foot pedals untouched and both exhausters closed. The compression springs behind the exhausters hold them closed normally. Well, now, the exhausters being normally closed, the reader will observe that (1) the outside air can find its way into the "pneumatic" through the channels and the top of the valve; (2) the long channel from tracker bar, over which the perforated paper moves to the valve pouch, will also contain any air that may have flowed into it when a perforation in the paper was registered with the tracker bar hole; and (3) through the little "vent," which is just a pin hole in a cap, the atmosphere flowing in from the tracker bar will also fill the reduced pressure chamber and therefore the entire bellows system, which is in connection with it. This is the normal or at rest condition.

Operation of Exhausters. If now, the foot is placed on a pedal and one exhauster pushed open, see what happens. Assuming that the tracker bar channel is sealed by the paper for the moment, as when no note is being played, it will be seen that the operation of the exhauster simply means that the whole inside cubical content of the player is enlarged by the exhauster being opened; the player, in fact, being made larger inside by just the volume of the exhauster. True to its nature, therefore, the air in the various parts of the player expands equally to fill up this space. But the illustrations show that a flap or strip of leather covers the openings between the inner wall of the exhauster and the interior of the player. This strip, however, is pushed aside by the rush of normal-pressure air into the empty opened exhauster, which continues until the pressure on either side of the strip is equalized. Therefore a quantity of air filling the exhauster, but at lower than normal pressure, is now trapped in the exhauster, since it cannot get back through the door which it opened once and is now holding closed (the strip); for this door is held shut by a spring just strong enough to keep it against the pressure on the inside of the player, and further, is of course held by the pressure now in the exhauster. But, the exhauster being now all the way open, and the pedal all the way down, the heavy compression-spring outside tends to close the exhauster again. Besides, the foot-pressure is now naturally released for the return of the pedal. Therefore the exhauster begins to close and in closing squeezes the air inside it, which is trapped there and cannot get back inside the player, until it is enough compressed to force its way out through the outer strip or flap into the atmosphere, being forced out by the closing of the exhauster. Once squeezed out, the exhauster is shut, and anyhow no more air can get back in through the strip or flap which presses on the outside of the exhauster. Therefore we see that one opening and closing of the exhauster has withdrawn a definite quantity of air from the interior of the player and has expelled it into the atmosphere. Therefore a "partial vacuum," as it is called, is set up inside the player; or, in other words, the pressure of all the air inside the player has been lowered.

Valve. This being the case, the atmospheric pressure on top of the valve holds it down firmly on its seat and shuts off the reduced pressure chamber from the outer air, whilst conversely the pneumatic is open to that air and therefore remains at rest.

Reduced-pressure Chamber. Thus the situation when the pedals are being operated is as follows: Pressure of air is being constantly reduced, inside the player, in the reduced-pressure chamber, in the tracker bar channel (though on account of the smallness of the vent, to a smaller degree), in the trunk channel between bellows and

ated continuously and the reduced pressure chamber always therefore is in a state of partial vacuum, being never in contact with the open air except at times through the very small vent), this normal air in the channel "falls" into the reduced pressure chamber as quickly as it can "fall" in through the vent (air being elastic in all directions, can "fall," as I call it, up as well as down). Therefore, partial vacuum again exists in the channel and under the pouch, so that the valve-stem is no longer held up with its buttons but again sinks down and is held down by the atmospheric pressure on its top button. Therefore again the pneumatic is shut off from the reduced pressure chamber and placed in contact with the atmosphere, so that it fills with air at normal pressure, and forthwith opens. This operation may be repeated over and over again, quite as rapidly as the piano action can operate, and in fact, even more rapidly; provided the necessary sequence of perforations is present on the paper roll.

This is the operation of the player mechanism. But we have yet to speak of one important accessory; the equalizer.

Equalizer. The equalizer is a reversed exhauster. Normally it is held open by a spring.

It is also, as will be seen, connected pneumatically with the remainder of the bellows system and with the upper action of the player. When the exhausters begin their work, the air in the equalizer expands along with the rest and part of it moves outward to the air, so that the pressure in the equalizer is also reduced. If the pressure is enough reduced to overcome the expansive power of the spring (which never exceeds 8 ounces per square inch of area on the moving wall of the equalizer and usually is much less, so that a displacement of about 3 per cent. of the contained air is enough to enable the atmosphere to balance the spring and neutralise it), then the equalizer starts to close. Whilst closing, it does no effective work, but is in fact a drag on the bellows. When, however, owing to an increase in the number of tracker bar holes open, or to slowing up of the pedaling, or increased speed of the motor, or to any other cause, the effectiveness of the exhausters is reduced for a time, the equalizer, forced by its spring, begins to open; and in opening becomes, of course, another exhauster, automatically displacing air from the player and holding it till the exhauster can take care of it and expel it. This is the function of the equalizer.

Of course, the reader is well aware that there are many variations on the simple system here described, but all depend on exactly the same principles, whether one or another kind of bellows be used, whether single or double valve system be adopted, and whether the most elaborate or the simplest expression devices be provided. In the next chapter, I discuss the general varieties of construction amongst the players usually met with.

Motor. The motor system is equally easy to understand. As will be seen by the illustration on the next page, the motor consists of small bellows called "pneumatics," mounted on a block which is perforated with one long tube running through it from the bellows, provided with ports called "suction ports" which penetrate to the outside of the remote surface of the frame. Each pneumatic is also provided with a port which runs between its interior and the outer surface of the same block. A slide valve slides over the pair of ports belonging to each pneumatic and is connected with a crank shaft by means of a connecting rod, the pneumatic itself being also connected to the crank shaft.

Operation of Motor. Now, when the bellows are operating below and the suction port is in pneu-

matic connection therewith by means of the tempo lever which opens a gate situated in a suitable gate-box, the air pressure in the suction tube is reduced. When, therefore a slide valve is in such a position that it covers both the suction port and the outer air port belonging to any pneumatic (see the illustration), the air in the pneumatic flows outwards into the suction port and thence into the channel and so to the bellows. This causes the outside air to press against the moving wall of the pneumatic and begin to close it. This closing moves the connecting rod and turns the crank shaft, which in turn brings the slide valve along till the suction port is closed and the outer air port exposed to the atmosphere, when the pneumatic again fills and opens, thus continuing the rotary motion of the shaft and completing it. When a number of pneumatics, usually four or five, are arranged around a crank-shaft at suitable angles, a continuous rotary motion is given to the shaft and the motor develops enough power to turn the take-up-spool around which the paper roll winds.

Motor Governor. The operation of the motor governor is equally easy to understand. As will be seen by the illustration on next page, air which travels from the motor passes into a sort of small

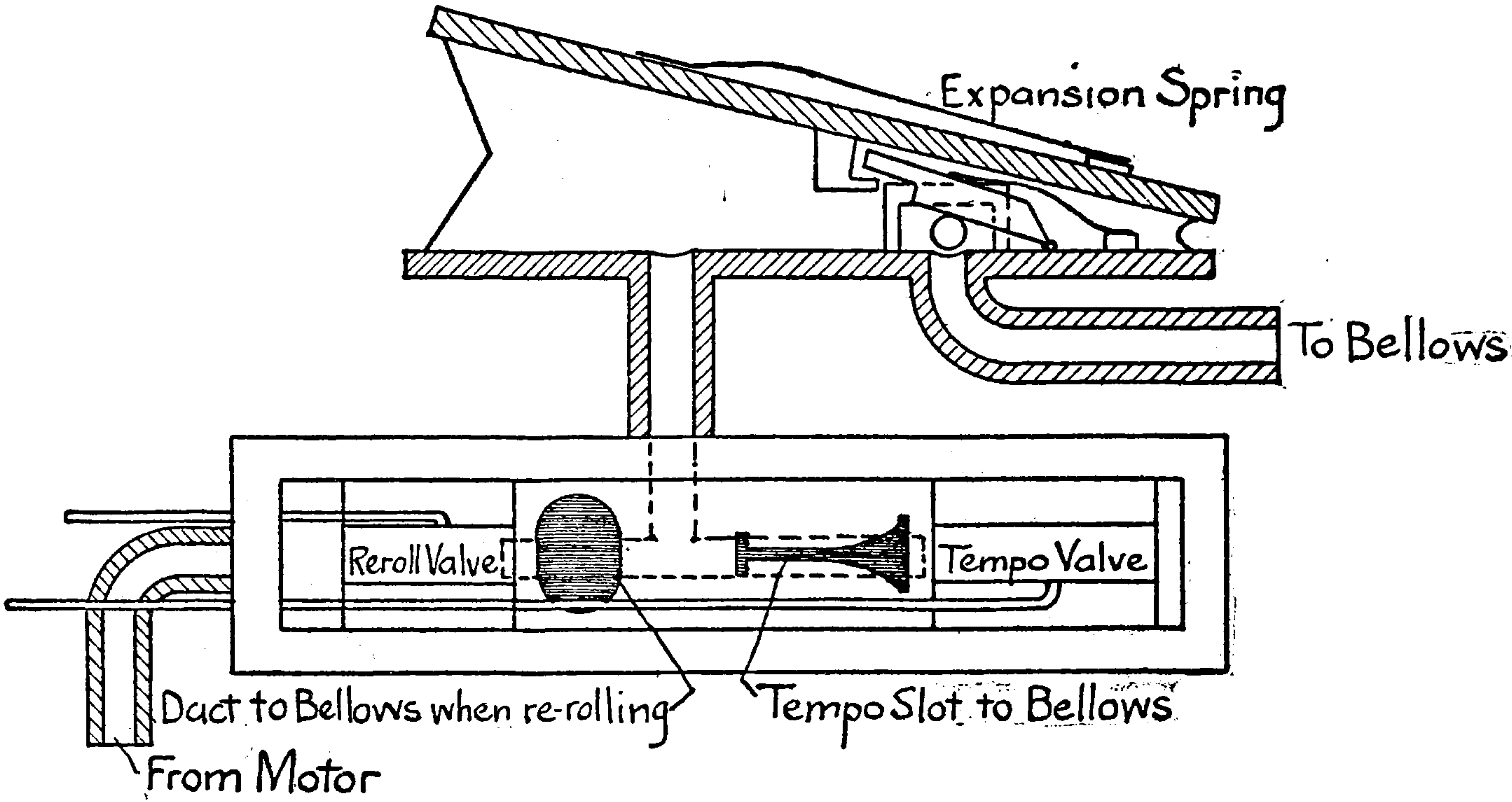

FIGURE 24.
Motor Governor and Tempo box in section (separation of re-roll valve from governor not shown).

equalizer, held open by a spring. In passing this, it goes through an opening which may be covered by a valve block, the movement of which depends upon the position of the moving wall of the auxiliary equalizer. The movement of this wall depends upon the power of its expansion spring. If this spring, for instance, is at such tension that it pulls back on the wall with a pull equal (say), to 3 ounces per square inch of the wall's surface, then the equalizer will close down as soon as the pressure inside is reduced enough to give the outside atmosphere more than 3 ounces effective pressure per square inch. In so closing it tends to shut off the travel of air through itself from motor to bellows and thus governs the motor so that *no matter how hard or how gently one pumps, that is to say no matter how much or how little partial vacuum there is,* the governor acts accordingly, closing or opening as required but always maintaining such an opening that increased velocity of air travel shall be balanced by smaller area of opening, or decreased speed by larger area, maintaining always the same pull on the motor and keeping its speed steady irrespective of the state of the pumping on the pedals.

Tempo-Box. To change speed, however, or to

peculiarities and so on, in just enough detail to enable the reader to recognize these when he meets them; and to understand their operation and duties.

Physical Facts. In conclusion, I append the following summary of physical facts, which should be learned by heart and carried in the memory:

1. Air, like all matter in any state, possesses weight; that is, air is affected by the universal law of gravitation.

2. Air, therefore, exerts pressure at the surface of the earth.

3. This pressure is about 14.75 pounds per square inch at sea level, but being equal and uniform in all directions is normally not felt.

4. The normal pressure of the air cannot be used unless a body of air in which the pressure has been artificially reduced is placed in opposition to it. Then it can be used.

5. This principle of "disturbance of balance" is the foundation of the entire player system.

6. The player uses very low effective pressure. Whereas a perfect vacuum would mean that the outside air could exert its entire pressure of 14.75 pounds to the square inch on the moving parts, it is impossible to obtain working pressure on the

moving parts higher than from $1\frac{1}{2}$ to 2 pounds per square inch. In other words, the degree of vacuum obtained inside the player does not exceed at the most 15 per cent. and is usually less than 10 per cent.

7. All air expands immediately when its container is enlarged or when part of it is withdrawn from its container without more coming in. This expansion reduces pressure, in proportion to its extent.

8. The player bellows operate by enlarging the containing space, causing the contained air to expand, then by means of suitable flap-valves expelling the displaced air on the closure of the bellows, and thus producing a state of reduced pressure inside the player; so that the outer air can operate against the moving parts thereof by pressure on their outer surfaces.

The above statement of principles applies perfectly to every possible arrangement of devices, parts or accessories found in any player mechanism made.

CHAPTER XII.

GENERAL CONSTRUCTION OF PLAYER MECHANISMS.

Piano-playing mechanisms have been developed after two general types. One of these is the detached or cabinet player, consisting of a separate mechanism enclosed in a case and mounted on castors so that it may be moved about readily. It is secured in front of the piano, with its fingers resting over the piano keys; and when the piano is to be used for manual playing, it may be moved away. This type, self-contained and involving no modification of the piano, was the first to come on the market, and the earliest specimens date from the year 1897. Some five years after their first appearance, their popularity was menaced by the "player-piano," as it came to be called, which contains both elements in the one case. From that time, the prestige of the cabinet player declined, until to-day one seldom meets it.

The other type is of course the "player-piano" of to-day, consisting of a player mechanism built

system. This is known as the "bellows-system," and to it are commonly attached various subsidiary devices, such as the motor governor, the expression governor, the action-cut-off valve, and the pneumatic sustaining-pedal action. The bottom action is of course connected with the top action (comprising the pneumatic stack and spool box with motor), by means of two main air tubes, one at the left side connecting with the pneumatic stack and one at the right with the motor.

Bellows. The modern bellows system is a highly sensitive organism, comprising two exhaust units connected to foot-treadles, and one or two equalizers. The double equalizer system is the more common of late. The two exhausters are each kept closed with a spring of about 7 pounds pressure, whilst the equalizers (if there are two), are spring-expanded (kept open) by springs respectively of 14 and 28 pounds. The latter, or high tension, springs are often re-inforced further by means of an extra wood-spring external to the equalizer and designed to come into action only when the equalizer is half closed. The idea of having two equalizers is simply to ensure that the bellows system shall not "go dead" on very hard pumping; which means that the two equalizers shall not both close up and remain closed until the tension has been relieved by momentary stoppage of pumping. With a good mechanism, well-made, and with heavy pumping, this might happen if the spring pressure on an ordinary equalizer were no more than 14 pounds total, for this would not be much more than 2 ounces per square inch on the wall of the equalizer. If the equalizer did remain closed it would simply be out of action, for it is plain [1] that it does no work till it begins to open after being closed. Hence the double spring-pressure on the high tension equalizer.

Two well known types of mechanism (the Auto-pneumatic Action Co.'s "Auto-De-Luxe" and the Standard Pneumatic Action Co.'s "Standard"), are provided with a special device in the equalizer known as the "crash bellows" (though just why this name, I do not know). This is simply a small bellows placed inside the equalizer over the connecting passage which runs outward to the main channel and to the exhauster, in such a way that a sudden raising of the tension level, due to hard pumping, will close down the small bellows over the opening and for the moment cut off the equalizer, thus giving the bellows that much less air-

[1] Cf. Chapter XI.

space to exhaust and therefore increasing its relative power. As soon as the effect of the sudden extra pumping work has evaporated, the crash bellows again open and the equalizer is once more thrown into operation.

Motor Governor. The bellows system includes always, whether immediately placed on itself, or at one side of and pneumatically connected with it, what is called a "motor governor." This device has been essentially described in the previous chapter and it is therefore now only necessary to remark that it is commonly fitted with a spring, adjustable for tension, and with some sort of adjusting screw for limiting the closing of its bellows. The speed of the motor is increased by increasing the tension of the spring. That is to say, the motor, irrespective of the tempo-valve, may be caused to move at a speed greater on any tempo valve position than originally it is adjusted to give on that position; and incidentally on all other positions. This general raising of the speed level on all positions proportionately may be accomplished by stiffening the spring. This simply means that the stiffer spring imposes greater resistance to the closing of the motor governor bel-

To determine the particular system used in any given case, one must know the player, or else must experiment with it to discover which method is used. The Auto-pneumatic and Standard players use the first system and the Gulbransen, the Cable Inner-Player and others use the second.

The point is that if the motor is unsteady on changes of pumping, the screw adjustment may be used to make correction of the fault. Such unsteadiness shows that the governor closes too much or too little, as the case may be. If the motor drags on light pumping, so that its speed falls, that shows that the governor closes too much and either its spring is too light or the adjusting screw must be turned to limit its closing. If the motor races on hard pumping, that shows that the governor closes not enough, or else that the spring is too stiff. If the general speed is right, then the fault is in the adjustment of the governor; which is corrected as described.

Expression Governors. Some players (Æolian, Auto-pneumatic, some types; Price & Teeple, A. B. Chase, Cable, Angelus, etc.), are fitted with an additional governor on the bellows-system known as the Expression Governor. The principle of its operation is of course identical with that of the motor governor, but the object of its existence is different. The motor governor exists to maintain a steady level of power, but the object of the expression governor is to enable quick changes to be made from a fixed governed low level to the ungoverned (high) level at which the exhausters of the bellows system are working at any moment. All sorts of detail differences are possible, and existing, with regard to the construction of such devices; but the type illustrated here (based on the system used in the Auto-pneumatic mechanism), will serve the purpose of description.

It will be observed that we have a governing bellows, or auxiliary equalizer, held open by an expansion spring. This bellows stands in the channel from pneumatic action to bellows so that air displaced from the action must flow through it on the way to the bellows. A small hinged valve block stands over the channel running to the bellows, and is pressed downwards by a spring on to the stop-block on the moving wall of the auxiliary equalizer or governor bellows. It is plain that unless (as shown in the illustration), the valve block were held up forcibly by the button on the threaded wire, it would drop down over its

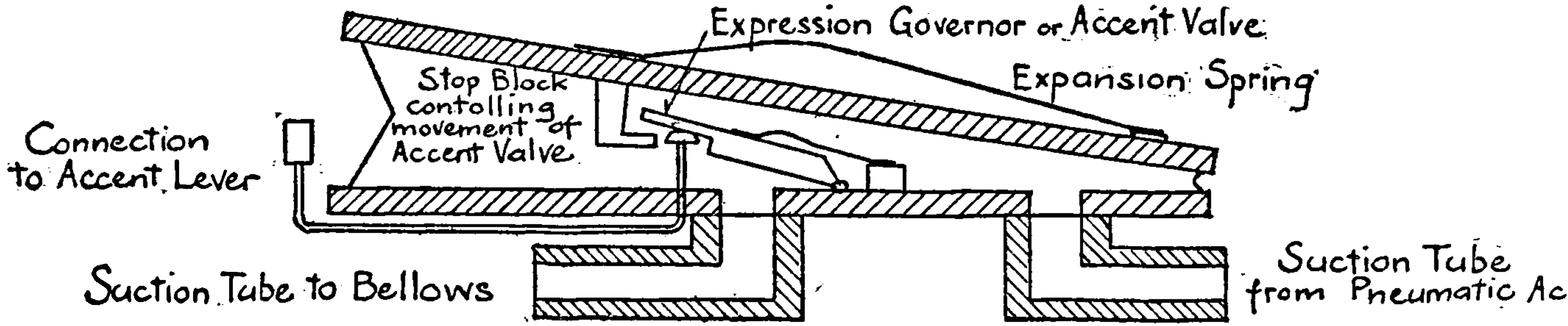

FIGURE 25.

Sectional view of Expression Governor (Auto-Pneumatic type).

being normally cut out of action, and then of having it thrown into action, to soften the playing when required.

The same effects could be had by a pneumatically operated pouch valve, with a button instead of a lever. Likewise, the accenting effect can be had by perforations in the roll operating on a pouch-valve as aforesaid.

Sustaining Pedal Pneumatic. In many players the sustaining pedal is operated by a direct mechanical lever system without the use of any pneumatic device. But of late years there has arisen a desire for automatic control of the sustaining pedal effects, through perforations in the music roll, and at the same time many retailers have expressed a preference for a pneumatically operated button instead of a direct lever. In this case a large pneumatic equipped with a valve system is placed near the bottom of the piano, adjacent to the damper lift-rod and connected with it so that the rod can be raised when the pneumatic collapses. This pneumatic system is connected to the main bellows system by means of a tube, and so, when the player is working, the vacuum chamber of the system is in a state of partial vacuum. Hence when air is admitted under the valve pouch or pouches by depression of a button or by opening of a perforation in the tracker-bar, the pneumatic collapses and the sustaining pedal action operates, lifting the damper from the strings.

Soft-Pedal Pneumatics. Another very common expression device is a pair of pneumatic systems, connected with the bellows system and placed on each side thereof, or above the line of hammers at bass and treble ends of the piano, whereby the hammer line of the piano, artificially divided by a split auxiliary rail, may be raised toward the strings of the piano, all together, or one half at a time. The method of operation is just the same as described for the sustaining pedal action, except that the pneumatics can be made smaller, since the weight to be overcome by each is not great. A pair of buttons on the key-slip control the admission of air under the valve systems of the pneumatics. When half the rail is lifted whilst the other half remains in normal position, the blow of the hammers which rest against the former, is shortened, with resultant softening of the sound produced by them. Thus, in a somewhat rough way, the accompaniment part of a composition may be subdued as against the melody voices.

Sometimes a pair of direct acting finger levers on the key-slip are used to lift the split hammer-rail without resort to pneumatic devices.

What is known as the "floating" hammer-rail is also sometimes used. This is simply an arrangement whereby the hammer rail and the ordinary piano soft pedal action are attached to the moving wall of the equalizer of the bellows system so that as the equalizer sways back and forth the hammer rail is moved forward towards, or back from, the strings. On hard pumping, when the equalizer closes up, the hammers recede from the strings; and on soft pumping, when the equalizer opens again, they approach the strings, thus modifying the length of the hammer blow in accordance with the pumping, and imparting a more flexible quality to the dynamic control of the player.

Action Cut-off. In all player-pianos the action is cut off from playing whilst the motor is rewinding the paper, by a door thrown across the main passage from action to bellows. When an expression governor is used, this cut-off is usually

the action playing, as is sometimes required for passing rapidly over a part of a roll which the performer does not wish to play. As sometimes built, the "Silencer" also opens the large re-roll valve in the tempo box, again without shifting gears, so that the motor can race ahead. This is only possible, of course, when the re-roll valve is controlled by a pouch instead of a direct action slide-valve.

Bleed-holes. All the valve systems described above as operating the various non-speaking pneumatics, require of course the usual "bleed-holes" or "vents" for the purpose of flushing out the air-tubes running from tracker bar or button.

Top Action. The top-action, so-called, of the player-piano consists of (1) the pneumatic stack (2) the motor and (3) the tracker-bar with its incidental accessory devices. Let us take these in order.

Pneumatic Stack. In the previous chapter I have described the principles of design in a pneumatic action controlled by a single valve. This description, roughly speaking, holds good for all players of what is called the "single-valve" type, which means the type where one valve only is used between the tracker bar and the speaking pneumatic. The so-called "double-valve" type is exactly the same, save that between the valve which directly controls the pneumatic, and the tracker bar, is another smaller valve called the "primary" valve. This valve is lifted by the air which flows down the tracker tube and in lifting exposes an opening of larger size than the tracker perforation, down which flows air to the "secondary" valve, which directly controls the pneumatic. The two valves therefore are interdependent, neither one being effective unless the other is also effective. It is not true, as may be seen by examining any double valve action, that the one valve operates the pneumatic if the other does not. The main reason for the use of the second valve is found in the desire to use a pneumatic larger than can be effectively exhausted by the operation of a valve small enough to be readily controlled by the amount of air which can flow down the tracker tube in any given time.

Only one vent or bleed hole is needed in the "double" action, as the secondary channels are flushed by their air flowing back into the primary chamber and thence out to the bellows.

Assembly. The pneumatic stack is assembled above the keys, with the pneumatics, in some sort

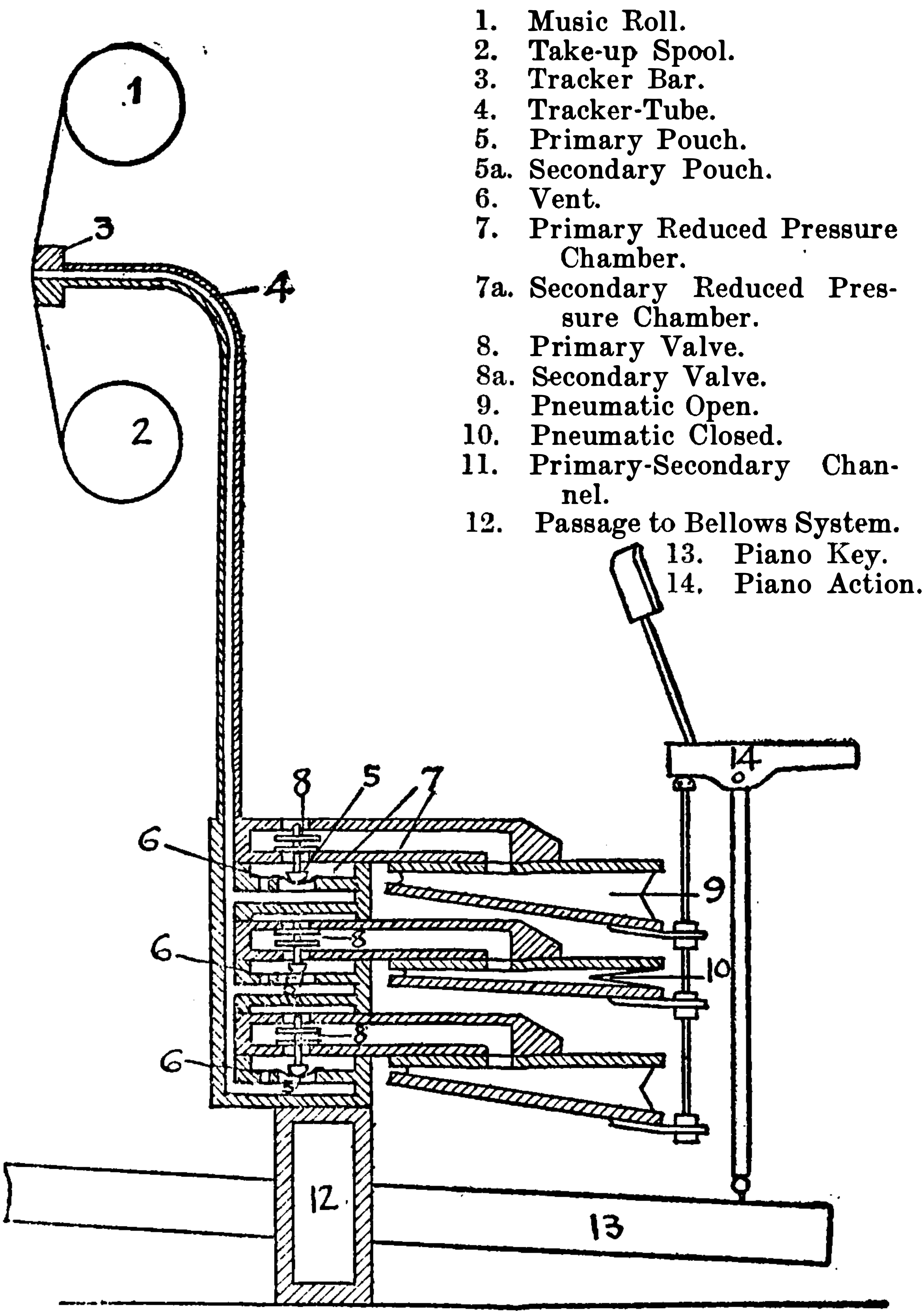

FIGURE 26.

Sectional view of Double-Valve Action showing pneumatics open and closed.

slide to each individual; whilst again some motors are made with double units, having two bellows, one above the other, working on each connecting rod. Some special types are also known, such as the cylinder motor of Gulbransen and his later models with their oscillating and rotary valves. But in all cases the principle involved is that which has already been described.

The spring-actuated motor of Melville Clark must also be remembered, but it needs no special description here.

The transmission is a simple form of gear set, whereby the motor may drive either the take-up spool, for winding forward, or the chucks on which the roll turns, for re-winding at the close of a piece.

Spool Box. The Spool Box is a rectangular open frame in which are placed the tracker bar, the take up spool and the music roll chucks, in addition to any tracker bar or roll shifting device that may be incorporated. Its various parts may be described as follows:

Tracker bar. The tracker bar is usually of solid brass pierced with 88 perforations, nine to the transverse inch, and with any extra perforations that may be required for the non-speaking pneumatic devices. From its rear the perforations branch out into tubes of rubber or metal which carry from each to its corresponding valve and pneumatic in the pneumatic stack. Sometimes (Clark, Gulbransen, etc.), the tracker bar can be shifted by a thumb nut in the spool box, so that any failure of perforations in the paper roll to register properly with the tracker-perforations, can be corrected. In other cases take-up spool and music roll chucks are moved by a mechanical device (Cable, etc.).

Extra perforations. Extra perforations used as follows: a large perforation at the left side for the sustaining pedal, small perforations in duplicate at either side for automatic accent devices (see *supra,* this chapter), and marginal small perforations for automatic tracking devices (see *infra*). In some cases the latter perforations are superseded by moveable tongues of metal or similar devices to press against the edge of the paper. Player-pianos of the electric-motor-driven type have also additional perforations to operate automatic start-and-stop pneumatics placed on the bellows system and working into tempo and action box.

Automatic tracking devices. Although there are a dozen different varieties of these, the intention in each case is the same and the principle similar. The idea is that if the paper shifts transversely in the course of its longitudinal travel, its own shifting shall operate devices to bring it back into line. The well known device used in the Auto-de-Luxe and allied players works as follows: At either margin of the tracker is a pair of very small holes leading to tracker-tubes which run into a valve-system controlling pneumatics, one to the outer and one to the inner, pair of holes. These pneumatics are connected with a lever system to the left hand music-roll chuck, so that this chuck is moved transversely from left to right, accordingly as the corresponding pneumatic is operated. The music-roll is always normally held hard against this moveable chuck by the pressure of the spring in the other (left-hand) chuck. When the roll travels as it should, in true register, its edges just cover each pair of marginal perforations. When, however, the paper shifts transversely, through any cause whatsoever, and so is thrown out of register with the tracker-bar, one pair of holes is covered, which lets air down the corresponding tracker-tubes, operates valves and the corresponding pneumatic, and causes the

65-note players. The 65-note player is a thing of the past, but of course many were made and are yet in use. They cannot be said to differ very much from the more perfected types of which they are the ancestors, save that the parts are larger and clumsier and on the whole much less accessible. In many cases the pneumatic stack is built below the key-bed so that it is necessary to withdraw the latter before one can get at the action at all. Although only 65 notes are operated, so that there are 23 fewer pneumatics than we need to-day, old pianos of this type are often quite astonishingly clumsy and huge.

It is well to note the following points as exhibiting differences from modern player-pianos:

1. The tracker scale is wider, having 6 perforations to the transverse inch. The roll is therefore somewhat wider also.

2. The rolls are pinned at the flanges, which means that a different sort of chuck to hold them is needed.

3. The action is sometimes placed below the key-bed and when this is so it is nearly always necessary to take out the entire bed to get at the action for repair or regulation.

4. Combined 65- and 88-note tracker bars were

used for a time after the first appearance of the 88-note player. In all of these it is well to look out for leaks in the tracker and for all the annoyances thereby caused. These combination players are now no longer made, however, except on order.

The Cabinet Player. Although the old cabinet or outside player is now obsolete, a great many of them were made, some with reed organs built into them and others embodying all manner of freak experiments. The range was either 58 or 65 notes and special music was therefore often necessary. The following hints may be found useful as a condensed guide to the construction of these old instruments:

Bellows. It will be found usually that the bellows of the oldest cabinet players were developed much on the order of the reed organ, particularly in respect of having a large equalizing unit and large exhausters. These bellows are essentially slow moving and do not lend themselves to quick changes of tension level. They are covered with the kind of rubber cloth used for the reed organ, and fastened at the bottom of the cabinet in such a way that to get at them it is necessary to take out the entire mechanism from the cabinet.

In fact, it will be found that usually it is not possible to get at any parts save the motor and tracker-bar without taking the whole thing from its case; in itself often a difficult and irritating job.

The various parts which go to make up the bellows system, such as governors, gate-boxes and action-cut-off valves, are usually found buried inside the bellows on the older cabinet players, and can only be reached through them.

Pneumatic Action. The valve system of the cabinet player is either of the simple single valve type described in essence in the last chapter, or of the primary-secondary type as described in the persent chapter. There is nothing special to be said about the make-up of such systems in the special case of the cabinet player, save that the valve boards are sometimes found glued together in such a way as to prevent any access to the pouches.

Motor. The motor is of the usual type, but often has only three units, which sometimes are placed at the bottom of the case. The spring-driven motor is used in the Apollo, Simplex and Needham cabinet players.

Expression. The expression control of the

Chapter XIII.

REPAIR OF PLAYER MECHANISM.

Within the meaning of the word "repair," as used in this chapter, I understand to be included all matters pertaining to the regulation and maintenance of players in good order during their effective life, as well as such direct reparations as are made necessary by actual breakage or destruction of parts. I do not propose to attempt an exhaustive listing of all the possible troubles that may occur, but shall give here some gleanings from my own experience and from much observation of others' work, with the intention of providing a general guide which will enable the learner to find his own way through the most difficult problems.

In the first place it ought to be realized that the number of possible troubles that can occur to a player-piano is limited. All may be traced to a few broad causes, and when these are known and understood, any problem that may arise can be reasoned out. I shall begin by discussing the possible troubles occurring to players that remain structurally and organically perfect, and shall then say a little about the work of repairing damaged and broken parts on older machines. In short, the first part of this chapter shall treat of maintenance, the second of actual replacements.

Leaks. The fundamental cause of more than half the ills which affect player-pianos is leakage. It is of course obvious that in a machine like the pneumatic player action, operation whereof depends upon the constant maintenance of a reduced pressure within the mechanism, any leakage of air inwards from the outside must be prevented at all costs. Yet it is also plain that this leakage inwards is inevitable to some extent, for the simple reason that the outside air presses upon the outer walls of the mechanism everywhere with a definite pressure directly proportional to the reduction of pressure within. The higher the vacuum within, the greater the pressure without. Hence it can easily be seen that there is everywhere a constant tendency towards the leakage of air inwards in all places where such leakage is conceivably possible. Thus, for instance, we know that when the button of the primary valve is thrown up, atmospheric air flows in beneath the button and into the secondary channel. Now, right operation of the mechanism depends upon the primary buttons seating upon their seats so cleanly that there shall be no leakage of air under them until they are deliberately raised by the operation of the paper roll. Any leakage under any of these buttons means that the corresponding secondary valves are operated, and then we have what is known as "ciphering"; which means, pneumatics speaking when no perforations in the roll call for them to speak. That is one illustration of the leakage problem.

It is equally plain that through leakage the pneumatic sustaining pedal devices operate when the control button is at rest. Leakage is responsible for the re-roll speed of a motor being maintained when driving forward. Leakage is responsible (when a re-roll is pneumatically handled), for the mechanism playing when re-rolling Leakage beneath the pouches of a tracking device may be responsible for constant bad tracking of rolls. And there are many other possibilities in the case.

Precautions against leakage. It is therefore clear that the maintenance of air-tight conditions

from the outside into the chest through their outer seats.

6. See that all hose connections are tightly on their nipples and if such connections have tightening bands, see that the latter are tightened accordingly.

Motor troubles. The pneumatic motor of the player mechanism is timed to run as follows:

2 feet per minute of paper to pass when indicator shows 20
3 feet per minute of paper to pass when indicator shows 30
4 feet per minute of paper to pass when indicator shows 40
5 feet per minute of paper to pass when indicator shows 50
6 feet per minute of paper to pass when indicator shows 60
7 feet per minute of paper to pass when indicator shows 70

and so on upwards to the 130 mark on the tempo dial, where the indication is for 13 feet of paper per minute to travel. These speeds are commonly tested on a test-roll which is marked out in feet and half-feet so that the time can be taken by the watch.

Test-roll. A test-roll which allows for the separate sounding and repetition of each of the 88 pneumatics, as well as for timing motor speed, is an essential element in the kit of the player-repairman.

Motor Slow. If the motor runs at speed slower than indicated above, the spring of the motor governor must be strengthened as explained in previous chapters.

Motor Fast. If the motor runs too fast, spring must be weakened.

Motor drags. If the motor drags on light pumping (does not run fast enough, loses speed), the governor closes too much. If the speed has been regulated through the governor spring, for normal pumping, the screw which is placed to limit the closing of the governor or its cut-off must be adjusted to keep the governor further open.

Motor races. If the motor races on hard pumping, the governor does not close enough. If speed is right on normal pumping, then adjust screw so as to make governor close a little more on hard pumping.

Motor hitches. If the motor runs irregularly and in a sort of gasping way, perhaps losing power rapidly or failing under hard work, as towards the end of a heavy roll, this probably means leakage under the slide-valves or incorrect adjustment of them. In the first place, see if the slides sit flat on their seats. If they do not, take them down and have them trued up. Wooden slides can be sandpapered flat. The seats should also be sandpapered and then burnished with powdered graphite (not grease, tallow or other fatty substances, but pure graphite only). In the second place, if the motor runs unevenly, disconnect slides and then carefully place each one in its true extreme position over the ports in both extreme positions alternately, marking the seat accordingly. Then adjust the connecting rods so that slides reach these positions correctly.

Motor races all the time. In this case the re-roll valve in the tempo box is probably being kept open. Adjust it accordingly. But if a silencing valve is used, look to this and see whether there is anything holding it open on the motor side; as for instance a leak, allowing air constantly to flow under the operating pouch and lift the valve.

Action plays when re-rolling. In this case it is evident that action-cut-off valve does not close when the re-roll lever or button is operated. In cases where a pneumatic device is used it is possible that leakage under the pouch or between the operating button and its seat may be responsible. Otherwise, a broken connecting rod is the most obvious thing to seek.

Action does not play. Action cut-off valve remains closed. Examine the manner of operation and apply remedies as suggested above.

been mal-adjusted by some previous repairer. Lost motion between pneumatics and piano action is also to be considered as a possible contributor to this defect.

Repetition good but power weak. Bleed-holes are probably too large and should be adjusted accordingly if player has adjustments for this purpose. But this defect is very unlikely to be observed in players with fixed bleed-holes.

Player plays hesitatingly. See if primary valve stems stick in their sockets or are too tight in them. This will cause primaries to move slowly and delay action of player. Similarly, see if secondary valves move slowly through stickiness of pins or other similar causes.

Travel of Valves. In almost all cases it may be safely set down that primary valves need not and should not rise more than 1/64″. Secondary valves need about 1/8″ travel in most cases.

Pneumatic ciphers. See above on Leaks. Ciphering is due to the valves operating independently of the paper, so that a pneumatic collapses as soon as pumping starts. Look for leaks in the tracker-tube, or dirt setting on valve seats, or leaks from channel to channel in valve boards or connections.

Pneumatic silent. If a speaking pneumatic does not collapse when it should, listen for a hissing sound. This would indicate a torn pneumatic. Otherwise see if tracker-tube or channels are clogged or valves held shut by dirt.

Dampers always off. Sometimes (see above, "*leaks*") air gets in under the sustaining device control button and keeps sustaining pedal pneumatic partly collapsed. Other similar defects may cause this pneumatic to remain collapsed.

Dampers do not rise on low vacuum. All pneumatic sustaining devices have the vice of requiring considerable power to work them. If they work well on lower power, then this means that bleed-hole and rise of valve are cut down so much that, although the pedaling is not affected, the operation of the pneumatic is slow. Vice-versa, if the pneumatic closes sharply, it makes a lot of noise and takes up much power. A happy medium is the only aim possible.

Soft expression. The expression governor can be regulated to determine what degree of power shall be available when the soft expression is in action. The stiffer the spring is made, the louder will the player play on soft expression; and vice versa.

In players which have divided soft expression, one half of the vacuum chest is affected by each governor. The action-cut-off valve is then also divided; one valve being required in each expression box. This should be remembered in dealing with such players.

Regulation in general. Of course, it would be possible to go on indefinitely setting forth directions for remedying possible troubles; but the foregoing covers the really essential points and the student should be able by careful study of the previous chapters to reason out for himself any futher problems of the same sort. It is mainly to be remembered that the player mechanism is to be considered well regulated when it plays well. If its playing is satisfactory to the user and to the tuner who cares for it there is really no more to be said. Certain things are requisite to the proper working of the player mechanism and these have been set forth above.

Patches and replacements. The actual replacement of parts which have become worn out is not often necessary but in old cabinet players and even on the older 65-note player-pianos still in use one sometimes finds it necessary to re-clothe bellows units, re-pouch valves and so on.

tra width to take care of the thin edge which is to be glued on the boards or walls of the pneumatic. Take a file and smooth off the edges of the pneumatic boards or walls, so as to get off all the old cloth that will come off. Then get good hot glue, spread it over the edges of one board and apply the cloth, smoothing it well down with the hand and ironing it finally with a small iron reasonably hot. Then do the same on the other wall of the pneumatic, allowing a little time for the first to dry. Be careful to see that the dimensions are preserved, especially as to width of opening when the cloth is glued on. For speaking pneumatics, a mercerized rubber-coated cotton is often used, gauging (L. J. Mutty Co. figures) 0045″ to .0075″. For motors the same firm manufactures a rubber cloth, either double or single texture, gauging .008″ to .015″.

Bellows Repairs. The corners of the exhaust units sometimes show signs of wear but the toughness of the cloths used and the comparatively slow movement of the units in operation permit effectual patching without any necessity for entire recovering. Patches should be of the same material as the original cloth and should be glued on with hot glue if the cloth is a jean or a twill; and with rubber cement if the old-fashioned rubber bellows cloth is the material.

Bellows flap-valves sometimes become leaky through porosity of the cloth. They can be covered with a strip of bellows-twill, or simply replaced.

Double texture jeans and heavy twills are used for covering bellows to-day. The old rubber cloth is virtually obsolete.

Pouches. To replace broken or cracked pouches, take off the old leather as carefully as possible and cut a new piece of the same size. Scrape glue-surface clean, put on hot glue and press down with a wooden block cut to fit the orifice. Kid is often used for pouch-leather on modern players, but on old ones sheepskin was sometimes used. The use of this latter should be avoided as it tends to crumble. In my opinion, a rubber-coated silk cloth is the best, and such cloth should gauge (see L. J. Mutty measurements) from .003 to .004 inch.

Squeaky Springs. Treat coiled springs with vaseline. If fan springs squeak see where the rust is in them and clean it out.

Squeaky Slides. Squeaky slide-valves in tempo boxes and elsewhere should be treated by smoothing off their seats and contact surfaces and rubbing on powdered graphite from a soft, heavy lead pencil. Never use grease in any form.

Overdrawn screws. Screws should always be countersunk and provided with metal washers when used to secure valve boards and other places where air-tightness is desired. Do not turn overdrawn screws, but withdraw them, plug their holes and re-insert. Overdrawn screws always mean leaks.

Leaky Tubes. Old rubber tubing is sometimes found crumbled and leaky. Do not bother about it, but simply replace it with new lengths. Old hose connections often leak also and it is better to replace them. Metal hose pipe connections should be well screwed down and if necessary seated on a coat of shellac.

Metal tubing does not often crack or otherwise suffer leakage troubles, but occasionally a jar or shock will crack such a tube at a joint. The best remedy is to cut out the affected part and join up with a piece of rubber tube; or else use the soldering iron.

Old Player-Pianos. Player-pianos made in the 65-note days were usually built with a child-like confidence in their infallibility; or at least one

subject of experiment and the repairman is ofttimes called on to use his skill on specimens of this sort.

In any case it may be said that the principles already briefly laid down in this book (and more completely in my "Player-Piano Up To *D*ate") apply to the old as well as to the new, nor has there been any radical alteration in essential methods. Principles, of course, are exactly the same to-day as they were twenty years ago; refinement in detail has been accomplished but scarcely anything more.

Cabinet Players' Individualities and Peculiarities. Similar observations apply to the older cabinet players, with certain additions. The older cabinet Angelus and Apollo were made with a 58-note range. The Angelus music rolled the reverse way. Apollo rolls were made without pins, whereas all other contemporary 58- and 65-note rolls had pinned flanges. Cecilian music was made with a long tracker bar provided with extra size perforations at the bass end. Such players had to have two tracker bars. Some Apollo players were built in a form known as "Apollo Grand," having an octave coupler which throws in an extra octave of pneumatics at bass and treble extremities.

In general it should be remembered that the cabinet players, even more than the old 65-note player pianos, were experimental. They therefore are found in vast variety of constructional detail, but it may always safely be assumed that their peculiarities are due rather to imperfect grasp of fundamentals on the part of their makers than to any excellences now unavailable or unused.

These brief hints and suggestions are given with the idea of suggesting methods rather than attempting to convey a definite answer to each possible definite problem. The latter task would be endless.

In conclusion let me give a short list of materials and tools that the player repairer should always carry with him.

Test Roll

Vacuum pump for tracker bar

Rubber tubing for tracker tubes

Hose (2 sizes) for main connections

Shellac in liquid form with bottle and brush

Glue (not fish glue)

Rubber cement

Kid (leather) for pouches

Rubber covered silk cloth for pouches

Rubber coated cotton cloth for pneumatics

Rubber cloth for pneumatics of motors

Special bellows cloth for bellows repairs

Raw-hide washers and strips for bearings of pedals, bellows, connections, etc.

Miscellaneous threaded wires and buttons

Leather buttons

Miscellaneous valve buttons and stems, valve seats, etc.

Other materials and tools will suggest themselves to the repairman as his needs and his experience alike grow.

A Last Word: It is not true that a good workman never quarrels with his tools; though perhaps a bad workman always does. A good workman never quarrels with good tools; and always with bad ones. Carlyle said, "Genius is nothing but an infinite capacity for taking pains." With these significant words I may fitly bring this book to an end.

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THE END

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