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S. HANSING

THE PIANOFORTE

Siegfried Hansing

THE PIANOFORTE

AND

ITS ACOUSTIC PROPERTIES

BY

SIEGFRIED HANSING

NEW YORK 1888.

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Preface.

Ten years have elasped since I wrote the preface to the German edition of this book in May 1888. During those years I continued my researches and investigations for a farther completion of practical instructions for the piano in its acoustic part, and therefore this edition has been enriched by much that is worthy of knowledge, both practically and theoretically.

The science of acoustics has ever won my attention, for the reason that I deem it the substance of all acoustic properties in piano building, and therefore it partly fills this book. The conviction has gained upon me, that the views expressed in the most acoustic dissertations are directly opposed to true facts and conditions. Treatise of mine, against the unnatural in the science of acoustics, have appeared from time to time in German as well as in English papers, and have greatly tended to uproot the old structure of the science. Though some few, still sustain the decaying edifice, sufficient material has been collected from various sides to build a new one corresponding to rational views. In this book then, I feel myself particularly inclined to bring to light and correct, as for as it his within my power, the erroneous views which being shared by the majority of piano makers have caused much harm to the acoustic construction of the piano. I have come to the conclusion that no one will succeed in making the invisible workings of a sounding body intelligible to the majority of piano makers for the reason that they have not learned to follow facts with the mental vision. The mental vision is capable of giving us a nicer sense of feeling and thus enables us to cope with the invisible. In practice, we are partially helped over the difficulties that arise in the study of the piano in its acoustic properties, by the mental vision. The sense of feeling can only be developed in the piano maker by enriching his mind with a knowledge and understanding of the nature of acoustics.

The study of music properly initiates its students only then when, together with the acquiring of technic, it arouses their souls by implanting in their minds a knowledge and conception of the tonal art. For piano makers also, there is such a study:— it is the science of acoustics. The early violin-makers pursued the study of acoustics after their fashion and they possessed a wonderful understanding of the undulations and vibrations of their instruments. All the old masters have probably passed through trying periods, in which they sought, by means of experiments, to further instruct themselves and increase their knowledge. They learned closely to observe and discriminate, gleaning from nature a definite method according to which they regulated their instruments. They must have understood the nature of their instruments thoroughly, being unable, however, to find scientific names to express the results of their experiments. Through untiring research and persistent experiments, they acquired and developed an acute sense of feeling and mental perception, which was of great assistance to them in their work and which is evidenced to-day by the instruments preserved to us. Not a prescribed measuring of surface with a compasses, nor yet a copy of a model, guaranties the complete success of an instrument, but the sense of feeling must render material aid, since only he, who, beside practice, has acquired a scientific knowledge of the nature of the instrument, can produce anything extraordinary. To this end I have found some special treasures of instruction and knowledge in the descriptions of experiments &c., contained in treatise on acoustics and other similar works. I am of the opinion that these treasures, to be applicable to the piano, must be at the command of an experienced piano maker, who is well versed in every branch of this trade. I disclose in the following work, the treasures which I have found during thirty years of experience as a pianobuilder, for the benefit of the piano, the pianobuilder, as well as for all those interested in acoustics in general and particularly for those who are interested in acoustics of the pianoforte.

March 1898.

Siegfried Hansing.

Contents.

Chapter XII.

Chapter XIII.

Chapter XIV.

Chapter XV.

Chapter XVI.

Chapter XVII.


SCHIEDMAYER & SOEHNE
STUTTGART

The Pianoforte:

and its acoustic properties.

Chapter I.

The production of sound.

If we set a heap of pebbles in motion, we hear a rattling sound as they move. This rattling sound is produced by the friction of the surfaces of the rolling pebbles. We observe that this rubbing or friction wears away a portion of the surfaces of both bodies. Hence we conclude that the material composing the stones was the factor in producing the sound. Therefore, as sound was produced by friction of the matter, it may be said that, friction acting on the surface matter of a body, causes it to produce sound.

The collision of two hard bodies causes a vibration in both; consequently, the matter of which they are composed is the factor in the production of sound ensuing from the shock or blow. Combining this fact with the one before stated, we assert: a body can produce sound when its molecules are set in motion. Upon close investigation we find that, without motion of its matter, it is impossible for a body to produce sound. In order to prove this fact, let us make the following experiments. If we strike an anvil with a steel hammer, a vibration will be felt in the body upon which the blow is dealt. This vibration produces a sound that lasts as long as the molecules of matter continue in motion. The tremor of the body indicates the activity of its matter. Deal a second equally strong blow upon the anvil with a felt hammer (provided this felt hammer possesses the elasticity and softness of the material), and no vibration will result. Since, therefore, the matter has not been set in motion, a production of sound is impossible. From the strength or weakness of the sound produced, we estimate to what a degree the matter has been agitated, following thereby the natural order of cause and effect. Bearing the above experiments in mind, we find that, when a hard body strikes with force against a hard body, the sound produced will be of proportionate strength or volume. However, if the force of the blow be diminished, or if the hammer be composed of softer material, the vibration is less apparent in a corresponding degree to the elasticity of the material and the force of the blow. The motion of matter is the cause of sound produced by the body, and we can estimate the degree of strength or weakness of this motion by the corresponding strength or weakness of the sound.

It is not the external motion of a body, but the internal vibratory condition of its molecules that produces sound. For example, in playing billiards, no perceptible sound is caused by the ball striking against a rubber cushion. If, however, the table were provided with a wooden cushion instead of a rubber one, assuredly a sound of proportionate volume would ensue. In the first instance, the rubber molecules cannot vibrate: hence the body is incapable of vibration. The power of a body to produce sound depends upon the material or matter of which it is composed. Should the molecules be independent in action, allowing a vibration, then a sound results; but, should all independence be precluded by inertness of the molecules, then a vibratory condition of a body is an impossibility. Molecular independence is caused by the hardness or tension of a body. For this reason, some bodies are more adapted to sound production than are others. For example, a steel plate lightly shaken will produce a noise like thunder; but it is impossible to produce a similar noise by the same means with a wooden plate of like dimensions. Steel and iron are better sound producers than wood. All metals do not possess in a like degree the same qualities for producing sound; lead, for instance, being inferior to wood. Solid and hard substances are best adapted to the production of sound; soft and elastic substances vice versâ.

Should we make thousands of experiments for the purpose of producing sound, we will find no single instance in which the matter composing the body has not been set in motion. Molecular motion arises from many causes, among which a blow, friction, compression, swinging, &c., may here be mentioned. I would like to call attention to sound produced by bodies in a swinging or oscillatory motion, in order to correct an erroneous theory which was formulated in the beginning of acoustic researches, and is obstinately adhered to, even in our time, chiefly for the reason that it is ably defended by Helmholtz in his work, "The Study of Tone Sensations as the Physiological Basis for the Theory of Music." The question arises: Is the sound produced by bodies—i.e., a piano string or a tuning fork, &c.—caused by the full undulations of these bodies in their entirety, or by the vibration of the matter of which they are composed? I had occasion to observe that the creaking sound produced by a wooden pole 40ft. long (one end of which was driven in the ground, and the other swaying freely in the air) was produced by the friction of the matter composing the pole, and not by the swaying to and fro of the pole itself. True, the external movement—the swaying of the pole—was the real cause or occasion of the sound; but the vibrations were so slow—being about two to the second—that the ear could not perceive them. According to the law of acoustics, there must be from 16 to 24 000 vibrations in a second to render a sound audible. Every one has heard the creaking and groaning sound produced by the violent swaying of the branches of trees during a storm, and all agree that this sound arises from the friction of the wood's molecules. Here we put the question, are not the oscillations of a tuning fork's prongs founded on the same principle as the swaying of the trees, or the above mentioned wooden pole? Are not these oscillations the cause that sets in motion the molecules of matter composing the fork? No one can dispute the fact that the matter is in motion, because the vibrations can be distinctly felt in the handle of the tuning fork, which of course can have no oscillatory motion in the sense here taken. In a subsequent chapter it will be proven that the oscillations of the prongs must produce a friction of the molecules in the curvature of the fork.

It is a well known fact that, without the aid and support of a sounding-board, the vibrations of a tuning fork or piano string slightly affect the aërial body. It will perhaps be difficult to prove that the resonance caused by standing a vibrating tuning fork on a board 1½in. thick will set the aërial body into motion by its transverse vibrations. I am convinced that the visible oscillations of the prongs of the tuning fork agitate the air more easily than can the vibrations of the above mentioned board, on whose surface no movement is perceptible to the eye; however, if the palm of the hand be placed upon this board, its vibrations are distinctly felt. Since, therefore, we know that the oscillations of a tuning fork cause vibrations of its molecules, and that such vibrations of a body produce sound, then why should we suppose that the sound is due to the oscillations of the fork in its entirety and not to the vibrations of its molecules?

In the chapter headed "Laws governing the Vibrations of the Piano Strings" it will be explained in detail that the sound produced by a piano string is also caused by the vibrations of its molecules. In corroboration of this assertion, a simple but very convincing experiment made by Pellisov by means of which he conclusively proves that it is not the undulations of the piano string, but the internal vibrations of its molecules that produce the sound or tone, may here be cited. Dr. Oscar Paul, in his "History of the Clavier," gives the above mentioned experiment in detail. He writes (p. 33) literally as follows: "Helmholtz maintains that, 'when we strike a string, its vibrations at first are sufficiently strong to be visible, and for this reason the tone is strongest at that time. Then the vibrations lessen, and in the same proportion the strength of the tone likewise diminishes.'" These are Helmholtz's own words. Dr. Oscar Paul continues thus: "Chladni had previously also made the same assertion, which Oersted strenuously contradicts in Gehler's 'Journal of Physics and Chemistry' (vol. 8, p. 241). Weber Bros., the genial experimenters, disputing Oersted's theory, assert: 'It is an undeniable fact that a swinging body may have an infinite number of vibrations; still, they are not perceptible to the ear. Only the strong, chief, principal vibrations of the entire body produce the tone.' The logical deduction would be, that the greater these principal vibrations the stronger the tone. Pellisov, however, in refutation of this conclusion, made an experiment with the lowest and longest string of a grand piano. Catching the string in the middle, he drew it away as far as possible from is points of equilibrium, then suddenly released it. The vibrations consequent on such tension extended more than half an inch from the line of rest. These vibrations grew gradually less and less extensive until the string finally assumed its undisturbed position. The remarkable fact remains, that the tone had ceased before the string had stopped vibrating. On striking the same string with a hammer the tone was full, yet the vibrations were scarcely apparent, — hardly to be measured.“

Neither the vibration nor the friction of the molecules is perceptible to the ear. When, like in Pellisov's experiment, a string subjected to a strong tension gives out no tone while its vibrations are still measurable, there certainly must be friction while it vibrates. For example, the shortest measurement of a string is the distance between its fixed extremities as it lies in its position of rest. When the string, well spanned, is set in motion, it naturally deviates from its line of rest in curvilinear vibrations. The distance between the two given points is greater in a curved line than in a straight one: hence we infer that these curvilinear vibrations result from the elasticity of the matter of which the string is composed. The string in its vibrations lengthens and contracts; this process produces a friction of the molecules. Without the aid of beats or shocks, simple friction of matter is not perceptible to the ear. For instance, if we rub a bottle with a dry cork no sound is produced until the cork has been moistened. By this means the cork adheres spasmodically to the glass and causes an uneven friction. To further illustrate, we apply a piece of cardboard to the smooth outer edge of a revolving disc, and no sound will be produced until the edge of this disc has been serrated, so that the friction is produced in shocks. By allowing such a serrated disc to rotate slowly at first, we can perceive every individual beat or shock; accelerating this motion by degrees, the beats will become indistinct, then merge into a rattling noise, then into a buzz, which finally changes into a perfect tone as the disc reaches its maximum rate of velocity. The syren is also an instrument used to enable us to ascertain the exact number of shocks in a musical tone during a certain given time.

It is a remarkable fact that our hearing, like our other senses, is affected only by shocks. No uninterrupted motion can affect any of the senses. The interruption of a motion makes us aware of its existence. When the senses have no means of remarking or measuring a motion, all susceptibility of the same naturally ceases. For instance, we all know that the earth revolves: we have no perception of these revolutions because they go on without interruption. Thousands of daily, unheeded occurrences might be cited to prove the aforementioned assertions. To illustrate further, should we riding in a railroad car whose movement is without jolt or jar close our eyes, we would fancy that the train were standing still. We can form no idea or estimate of the rate of speed, because the senses fail to perceive any arrest of motion. Opening our eyes and looking out of the car window, we receive the impression that all external objects are coming towards us, passing by the car at a relative rate of speed. We are under this impression because we still have the sensation that the car is not in motion. Would we reckon the rate of speed of a moving train, we must notice the intervals between the jolts: these intervals must be of uniform duration, and must not succeed one another too rapidly nor yet too slowly.

To revert to our experiment of the disc and cardboard. We find that the beats or shocks will be so much the more plainly observed if the intervals between them are of long duration. This same applies to the jolts of the car. As the beats on the disc by accelerated motion produce a rattling noise, so in the car the shortening of the intervals between jolts occasioned by increased speed also causes a rattling noise. When the intervals between the shocks are uniformly short enough, a certain rhythmic, swaying motion is caused. Can the ear fail to be sympathetically affected by this rhythmical motion, which is like the vibratory motion of a sounding body? To determine the rate of speed in which a car moves, do not count the jolts that occur within a certain time, but estimate the duration of the intervals between the jolts. Our ear is an organ of sense, and is capable of perceiving shocks and interruptions, and can distinguish the pitch of a tone by the duration of the intervals between beats or shocks. Pitch depends on the rapidity of vibration. The time required by the ear to measure intervals for tones is from $\frac{1}{16}$ to $\frac{1}{35000}$ of a second. A test that I made to ascertain the limit at which my ear could intelligently distinguish the highest tones proved that I could distinctly hear eight lined C giving 33408 shocks. This signifies that my ear could measure the interval of $\frac{1}{33408}$ second of time. Above this pitch my ear was unresponsive. In listening to the eight lined C I experienced the sensation as if the tone were accompanied by the pricking of a fine needle in my ear.

Professor Richard Zeckwer, director of a musical academy in Philadelphia, where the test alluded to was made, and who possesses a remarkable collection of acoustic apparatus, declared to me that he had made a number of experiments on many persons, and that eight lined C formed the limit of audibility for ordinary ears; that it was only in exceptional cases that C♯ with 37584 beats could be perceived, and that beyond this the beats and intervals are of so short duration that they no longer affect the ear, and no musical sound is heard.

With what nicety the ear can distinguish the difference in pitch between two tones is ably explained by J. Kerr Love in the *Naturwissenschaftliche Rundschau* ("Review of Natural Science") as follows: "Two stopped organ pipes which by means of movable stoppers could be lengthened or shortened at will served as tone producers. The shifting of the stoppers was effected by carefully worked screws, which limited the minimum alteration of length to $\frac{1}{840}$ of an inch. The pipes were supplied with air by a bellows which had a uniform inflation and exhaustion of 2in., so that equal strength, duration, quality, neatness, precision, and correctness were given to the separate tones. The persons to be examined remained at a stated distance from the pipes without changing position, and were required to tell if two consecutive tones were of the same or different pitch, as the case might be. About five hundred persons were examined, among them some with untrained and others with highly educated musical ears. The results were the following: it was almost impossible to calculate the exact discernible difference in pitch in the cases of the unmusical or slightly musically educated ears; but, excepting cases of 'tone deafness,' it was brought within the range of from $\frac{1}{18}$ to $\frac{1}{40}$ of a semitone, $\frac{1}{24}$ semitone being the average limit. Practised musicians—i.e., violinists, tuners, and some piano players—could perceive with ready ease and certainty a difference of pitch as small as $\frac{1}{64}$ to $\frac{1}{80}$ of a semitone. The ears of all persons, especially those of the uneducated, are more sensitive for acute than for grave sounds: hence the differences were more readily discovered when the pitch rose than when it tended downward.“

The ear is capable of appreciating the relative pitch of a sound in relation to another, although it may not ascertain precisely the absolute pitch. The fact that the ear is only susceptible to jolts, beats, or shocks cannot be refuted, as it can be incontestably proved; and this again leads to the fact that the ear determines the pitch of a tone by the duration of the intervals between the beats. It is a fact that our ears cannot count the number of beats nor fix the definite time in which they occur, but it notices the duration of the intervals between these beats. According to a theory of Helmholtz and others, our ear is not an apparatus for measuring intervals, but it is a real musical instrument. An extract from an article in a New York paper (which evidences that the author holds the same opinion as Helmholtz) follows: ”The geometrical discrimination of the objects heard is almost entirely lacking. We only hear directly, — first how strong and secondly how high a tone is, — i. e., the rapidity of its vibrations. The ear, besides distinguishing the three qualitative, distinct fundamental sensations, is susceptible to innumerable ones. In the human ear are numerous filaments or fibres, each one tuned to a given tone or pitch. A tone striking the ear causes these filaments to act precisely as the strings of a piano into which one sings. Only those strings which are in accord with the tones sung will vibrate. The auditory nerve perceives the vibrations and announces to the brain that filament x vibrates; this implies that we hear the tone x."

In connection with this, John Tyndall says in his book, "Sound" (p. 399, last paragraph): "Finally, there is in the labyrinth an organ, discovered by the Marchese Corti, which is to all appearance a musical instrument, with its cords so stretched as to accept vibrations of different periods and transmit them to the nerve filaments which traverse the organ. Within the ears of men, and without their knowledge or contrivance, this lute of three thousand strings has existed for ages, accepting the music of the outer world and rendering it fit for reception by the brain. Each musical tremour which falls upon this organ selects from the stretched fibres the one appropriate to its own pitch, and throws it into unisonant vibration. And thus no matter how complicated the motion of the external air may be, these microscopic strings can analyse it and reveal the constituents of which it is composed. Surely, inability to feel the stupendous wonder of what is here revealed would imply incompleteness of mind; and surely those who practically ignore, or fear it, must be ignorant of the ennobling influence which such discoveries may be made to exercise upon both the emotions and the understanding of man."

We judge from the words of the same work (German edition, which was translated by Helmholtz) that the existence of an ear harp is doubtful. Following is a quotation from the last chapter: "In these closing remarks I have endeavoured to show the opinions held at present by the principal authorities in regard to the forwarding of the sounding motion to the auditory nerves. I ask you to consider these opinions as possible, but not as established facts. They show the phenomenon in a connected and comprehensive form; should they ever be replaced by a theory truer and more extensive, the established truth will surely not lessen the wonder."

According to the "wave theory" of Helmholtz and other authorities, an ear scale must exist in the ear to distinguish pitch. The theory upon which this book is based, which claims tone to consist of beats and intervals, requires no such wonder harp. A lecture delivered by me was published in the *Musik Instrumenten Zeitung* of Berlin, and published by the American *Music Trades* in December, 1895:—

"I have here a large piece of flannel, folded four times. If any gentleman in the audience will take the slight trouble to place these eight layers of flannel around his head, leaving only breathing space, he will discover that he is still able to perceive every tone from the piano, even when I have added two feather pillows to the wrapping. Now, gentlemen, you will join with me in declaring that it is impossible for waves of sound to work their way through such cushioning. Why, then, should we allow the wave theory to stand, when it is thus proven that the waves are utterly useless as far as our hearing is concerned? It is much easier to believe that the transmission of notes—or, rather, the acoustic sound from sound producing bodies to the ear—is carried out by some kind of electro-magnetic agent, by which the microscopic fibres of the ear are used as a kind of electric battery. This is much more probable than that each fibre is specially prepared for the reception of a distinctly defined tone, thus rendering possible the recognition of numberless different tones.

"Marchese Corti claims to have discovered this wonderful harp in the ear; Kolliker counts 3000 fibres, each of which is to be regarded as a cord. But this number falls short, by far, of the differences in tone which the ear of, let us say, a good tuner is able to distinguish. Why, gentlemen, in tuning two chords there remain two different sounds as long as the slightest deviation is noticeable. Hence, there would have to be two fibres to enable the perception of two tones. Kerr Love has discovered that, in the case of organ pipes, good tuners are able to distinguish $\frac{1}{80}$th of a semitone. I can assure you that a good pianoforte tuner must be able to distinguish much smaller differences. If we reckon according to the above proportion for four octaves, then there must be 12×80=960 fibres for each octave, or 3480 fibres for four octaves. Even if we take into consideration that deviations of sound are more perceptible on the middle registers, and add only half the number of fibres for the additional three octaves on our present pianos, the ear of a good tuner must have more than five thousand cord fibres. Now, if you remember that Dame Nature would have to tune these five thousand, or even only three thousand, little cords at the birth of every individual, you will acknowledge that such a miracle is beyond a healthy conception.

"What would you think if I were to inform you that I know a person who is able to distinguish the slightest difference in the notes of all octaves except the middle ones? Would you believe me? You know that Nature makes many mistakes: could you imagine that these particular fibres are deaf, or at least crippled? Certainly not, for you know of no such case; and, if you were to seek advice from our friend Dr. Kahn, he would also tell you that he has never met such a case in his professional career, and that it is not likely to occur. Yet, if this 'harp of hearing' really existed in the ear, such cases of defect as the one I have suggested could not be rare, but would be familiar to all of us.

"Here is another argument against the existence of this harp. You are aware that people can train their capability to distinguish tones, even during riper years. Do you think it possible that one may, by the simple act of training, cause new fibres to grow and come into tune? No, just as little as a man can get two new ears to grow in addition to those which he already possesses, just as little is it possible to grow three thousand additional fibres after a period of thirty or forty years, if he received only three thousand at his birth. There are no such absurd creations in the ear, for the simple experiments prove to us how tone originates, and how the different tones can be distinguished from each other.

"Here is a tuning prong of extraordinary dimensions. It is thirtyseven centimètres long, each point measuring twenty centimètres. Although the amplitude of reverberation is six millimètres for each point, you cannot hear a sound from the prong as I strike it upon the soft part of my knee. Unless you make use of the assistance of resonance, you cannot hear anything until you place the vibrating points near your ear, in which case you will hear the G♯ of the great or lower octave. To illustrate the manner in which sounds become perceptible, I put the vibrating prong in touch with the end of this postal card. You hear a rattling noise, and are not a moment in doubt as to its origin.

"You see how the prong executes a number of quick blows upon the card, and know that these blows are caused by the quick vibration of the points of the tuning prong. You also perceive that these blows make audible sounds, just as you can hear me tapping against the card with my finger. I will now proceed to give a periodical number of taps with my finger' producing an equal number of periodical sounds from the card. For this we require a time measure, and I choose a certain rhythm, —thus, 1—2, 1—2, &c. Now I double the time in 1 and 2, and 1 and 2, &c., and we thus get the double number of taps in the same period, the interval between the taps having been correspondingly shortened. In connection with sounds resulting from periodical taps we can speak of a number o sounds, but not of a number of time intervals; for the pause of one sound to the next is, throughout the whole number of sounds, equal. If we speak of the extent or length of an interval, it is, for example — if twelve taps or sounds are produced in a second — one twelfth of a second.

"Wenn I use the tuning prong on the card you cannot distinguish the individual taps; yet you would notice an increase in time, for the ear distinguishes very distinctly if a drummer executes a second roll quicker than the first. This ability to distinguish the difference must be remembered in contemplating the formation of sound.

"As often as the point of the prong knocks the card out of position a loss of time occurs which prevents the full number of vibrations from being translated into taps. In order to realise the effect of the full number of vibrations, I now put the other end of prong to the card, and thus I prevent all loss of time. The result is tone, only slightly interspaced with the rattling noise. If I hold the prong carefully at full length against the rim of this straw hat, I obtain a note similar to that produced by an organ pipe. If I draw the prong along the edge of the hat, after the manner of a violin bow, a note is produced which may be mistaken for one coming from a bass viol. After these explanations you can hardly doubt that a number of periodical blows which the prong has given to the card or the hat have produced an equal number of sounds. On account of the quick succession of these sounds our ear is unable to separate these sounds: hence they must appear as one continuous note.

"That our ear nevertheless distinguishes the intervals between the sounds I have shown by my illustration of the roll of a drum; but I will prove my point still more forcibly by the use of a resonant body. Here, gentlemen, is a common tuning prong in the A of the middle octave. The tone it gives forth is produced by 435 vibrations or blows, and we regard it as the normal tone for the tuning of our instruments; but that is another matter. Here is a water glass, which I hold with its longest extension horizontally. As soon as I put the stem of the vibrating prong in contact with the glass, you hear a rattling noise. From what I have said before, you know that this rattle is the result of a periodical number of taps. The stem of the prong being unyielding, cannot. like the points, execute transversal movements, especially as my fingers prevent them still further. The taps, therefore (which we feel very distinctly when the larger prong is used), must travel along the length of the stem: they are, therefore, longitudinal instead of transversal. These longitudinal vibrations produce taps on the glass in the same manner as the transversal vibrations produced them on the postal card before, and the force of the blow causes the prong to recoil in the same manner as the card recoiled from the points of the prong.

"You have now a clear illustration of the manner in which resonance is developed. The factors which cause the tone are, in this case as well as in the other, blows, sound, and intervals. Now, gentlemen, if the note were not produced by these three peculiar agents, but emanated, as natural philosophers of the school of Helmholtz still assert, from a combination of waves, then it would be impossible to produce sounds different from those which the vibrating prong gives out. But I can give you a still better explanation of the matter.

"If I bring the stem of the prong into contact with the table in a very careful manner, I can, in some measure, repeat the rattle. I wish to draw your special attention to this experiment, for you will distinguish amidst the rattle the *contra* or lower A, though not very clearly; thus, a note fully three octaves below the natural A, in which the prong is tuned. As I press the stem of the prong more firmly on the table, the note gradually changes from the *contra* A to an octave higher, and finally reaches its normal sound. If, during a repetition of these experiments, other notes are also distinctly audible, you need not be astonished. The whole thing depends upon the number of vibrations which, out of a total of 435, are transferred to the table. As the octave notes are formed by vibrations in rhythmical accord with those of the normal note, the octave A's naturally predominate in the accompanying notes. What counterproofs can the adherents of the continued wave theory offer to these simple facts? I leave the continued sound wave manufacturers to answer."

To illustrate the sensations consequent on regular and irregular intervals, I will again revert to the ride in a railroad car. We have all ridden in cars, and have followed the inclination to keep time with the jolts that recurred at regular intervals, by counting one, two—one two. The motion of the car, with its monotonous regularity, causes us to be prepared for the jolts, and in consequence our notice of them is considerably weakened. This effect is heightened by the car assuming a swaying, rhythmic motion, in which the passengers involuntarily join. To those interested in such matters, it is highly amusing to observe how all suspended objects conform to this rhythmic motion, swaying in accurate time. It is evident that a car can have this swaying, rhythmic motion only when its jolts recur at regular intervals. This rhythmic motion is very soothing, engendering a most agreeble comfortable feeling. The same phenomena are apparent in a sounding body—i.e., if in a sounding piano string we observe the transversal vibration, we notice how they have a certain time measure, according to the pitch. Impelled by the rhythm of these vibrations, the agitated molecules of the string regulate their activity, as must all objects affected by them. Having thus far instructed ourselves in the nature of a sounding body, we find that an ear harp is not requisite to the tone sensations. The instruments of our ear receive the beats as they come periodically from the sounding body, and a rhythmic movement, corresponding to the time measure of the beats, results in them. This rhythm is transmitted or communicated to the nervous system, and is recognised as tone colour. We may therefore say that the ear recognises the tone colour through the rhythmic motion of sounding bodies; as these bodies produce tones of different pitch, the ear only forms an accurate discernment of the rhythmic motion of a tone when two or more tones are simultaneously produced. Thus it is difficult for a singing master to give a particular note without the aid of an instrument. If he sounds a tuning fork he can readily determine from the rhythm of its tone the rhythm of others. A rhythmic motion affects us pleasantly; an irregular motion produces a rough, jarring effect. Should an unevenness of the track or road bed cause a number of sudden, irregular shocks to the car, the rhythmic motion is interrupted, and by this we are disagreeably affected. If the shock is periodically repeated, so that a new measure of time is established, and we count say one, two, three, and four, one, two, three, and four (instead of one two, one two, as we did before), the car has resumed its rhythmic motion. Just as we feel the difference between the jarring and regular motions of the car, so does the ear discriminate between noises and musical tones. Noises are caused by impulses which are not regular in intensity or duration, or are not periodic, or they may be caused by a series of musical sounds occurring simultaneously, so as to produce discords; for example, when a hand is placed at random on a key-board. Musical tones are produced by periodic and regular beats coming in quick succession.

In order that a body may produce periodic beats it must assume rhythmic motion, which will be apparent in the oscillations or undulations of the sound giving body. The vibrations are a time measure for the beats, and this measure has the same relation to tone as time has to a piece of music. Rhythm is a division of time into portions by a regular succession of beats. The ear discerns the form of rhythm by the measure of the beats. For example, the rhythm of a waltz is produced by a three-four measure and of a polka by a two-four measure. The ear finds a certain rhythm in a tone through the time division of the vibrations' time measure. So, for instance, the prime receives four-four time, and the fourth, accordingly, three-four time.

As the ear distinguished the waltz from the polka by the difference in rhythm, so it now distinguishes between three-four and four-four time measure of the vibrations, and places the prime and fourth accordingly. We cannot play a waltz and polka together without shocking our sense of rhythm, but we can sound a prime and its fourth simultaneously without producing any unpleasant sensation. The reason for this is that the rhythm of these tones changes, as was explained in the example of the rail road car. If the tonic (prime) and its fifth be struck together, the fifth will be observed to have three beats to the tonic's two. Every rail road track has two parallel rails. We will imagine that the prime (tonic) is represented by the right hand rail, by a measure containing four bumps, each bump causing a jolt to the car. The left hand rail represents the fifth (dominant), its measure containing six bumps. The bumps must be equally divided on their relative rails, and the two rails must be exactly of the same length. Now, when the car commences to move it will receive the first shock or jolt on the left hand. the second on the right hand, the third on the left, the fourth on right and left simultaneously, &c. The car thus has one jolt on the right, two on the left, and one on right and left at the same time. The time measure is now one and two three, one and two three, &c. This subject will be referred to in detail in the chapter headed "Combination Tones".

In this rhythmic motion lies the magic power of tones, a power which they exert over other bodies. Even as the articles swayed in rhythmic motion with the car in which they were suspended, so we also find that objects are affected by the rhythmic movements of a tone. Various experiments, among them the dancing gas lights, confirm this statement beyond dispute. It is the rhythm of music which excites the young people to dance, and causes elder persons to mark the beats by keeping time with their feet, heads or hands. What causes the sensations consequent upon the rhythmic motion of music? Only the sympathetic action of the organs of the ear.

From the foregoing discussions we come to the conclusion that tone is a refined sound. The following may serve for farther explanation: We know that the distinguishing of refined sounds from ordinary sounds despends upon our musical instinct. A refined sound may be recognised at a very low stage: for instance, in the rattling of a drum, which instrument cannot be called a tone instrument. The musical perception on hearing the beating of a drum is aroused by the time of the beats. The time gives the beats of the drum a certain rhythm, and rhythm is the beginning of all musical perception. A single tone stands on the same degree or stage of our musical perception, as the rattling of a drum for its refinement also arises from a rhythmic succession of beats. Ordinary sounds either lack every rhythmic motion, or else this motion has such slow time that no musical perception can be aroused thereby. At the lowest tones circumstances prevail which prevent an exact calculation of the least number of vibrations at which beats may be distinguished as tone.

Apart from the fact that some ears are more susceptible for rhythmic motion than others, much depends upon the softness and roundness of the beats, at what number of vibrations they may be distinguished as tone. For instance, if the beats are especially hard and sharp defined, the rhythm cannot easily overpower the rattling of the beats; and for this reason it is not always true that a tone will be produced at sixteen or seventeen double vibrations in a second. The lowest tones are always accompanied by a rattling of the beats: this is demonstrated by the organ. A drummer who is capable of giving twentyseven drum beats in perfect time during one second will produce a tone subcontra A. We recognise such able drummers in the strings, which can perform this feat most perfectly.

The experiment of Pellisov, which I mentioned before, proves plainly that the vibrations of a string are not audible, far less the beats, especially those which are transmitted to a resonant body by the strings.

In order to obtain a rhythmic succession of beats, much as with clockwork, a regulator is required, this regulator of the string being the transversal vibration. The transversal vibrations stand in close connection with the longitudinal vibration. This longitudinal vibration (arising from the expansion and contraction of the string) reproduces the shock which agitated the string into beats and transmits them to the resonant body. Consequently, the reproduced beats must occur in rhythmic succession according to the time of the vibrations of the strings.

Following the progress of the rhythmic beats of a tone, we find that, in order to distinguish one beat from another, an interval must exist between them, otherwise there would be but one beat of indefinite duration. As the octave tone has twice as many beats during the same time as the prime tone, the interval between the beats of the octave can be but half as great as that of the prime tone, and the time is twice as fast. Hereby the ear distinguishes the tone proportions from each other, and more; for if, for instance, a prime and fourth are concerned, the time of these tones stands as 3 : 4, and sounding the two tones together the beats falling into one another produce 3-4 time. Hereby a certain rhythm in the movement of the beats is caused as it exists in no single tone, and this rhythm again is distinguishable from the 2-3 time of the beats, — for instance, of a prime and fifth sounded together. From a perfect rhythm and an imperfect one, the ear distinguishes the consonance from the dissonance, &c.

The development of tone and the perception for it arises through well known musical laws, which must be familiar to every musician as a rule for musical impressions. Wherefore shall we push aside a process which harmonises with our musical instinct, and still marvel at the incomprehensible wonder of a harp in the ear? This harp places tone apart from all musical sounds. Separated from these sounds, tone remains an unnatural, wondrous phenomenon, which does not seem less strange because of the three thousand microscopic fibres which Nature is supposed to tune so perfectly that each fibre is ready to repeat a tone coming from without to which the fibre corresponds.


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Chapter II.

Properties of tone.

The ear recognises two properties of tone, one of which is called pitch. Pitch is recognised by the ear through the duration of the intervals. As we speak of colour in regard to light, so it is customary to speak of colour in regard to musical tone. The musician seeks through a rhythmic combination of tone pitch to please the ear, just as a painter endeavours through a happy blending of colours to delight the eye. From this standpoint then, we consider pitch as the colour of tone, or "tone colour." This expression, musically considered, is surely correct. The musician does not, like the philosopher, estimate pitch carefully by the number of vibrations, but reckons by the impression produced by what he hears. The eye distinguishes different colours in light, and the ear discerns different colours in tone. Therefore, as one speaks of a picture in painting, a musical composition may legitimately be called a tone picture. The expression "tone colour" is not a new one: still its nature has not been correctly understood.

Character is the second great property of tone. The ear recognises the tone character through the nature of the beats by which a body renders its sound audible. In contradistinction to tone colour we can designate tone character as sound colour.

We may speak of the number of beats in a tone, but the intervals between these beats are so regulated that they are of uniform duration: hence there is only one interval.

Sound may be produced by any body, which need not necessarily be a musical instrument. For example, if a glass falls to the ground its breakage will cause sound. Wood and most metallic substances give forth sound. We observe the piano maker rap on the soundingboard, to judge its value for his use by the sound produced. Sound forms a portion of tone, without entirely constituting it: for when we speak of sound, pitch is not considered. Thus we say: the clear ringing or dull sound of a trumpet; the violin has a good or bad sound, &c. Unfortunately, however, great confusion has resulted in the proper comprehension of the two properties of tone, which arise from beats and intervals, because the correct distinction has not been maintained between them. Even renowned writers on acoustics have confounded the meaning of the two terms. Before we pursue this subject further, we must acquire a clear conception of the true meaning of the word "sound". For this purpose we go into a manufacturing town where we will find ample material for illustration." It is a well known fact that we can readily trace the cause of many sounds, despite all the confusing noises. For instance, we hear the clang of hammered iron, and recognise the metal by the sound produced. Between the measured blows of the hammer we make out the grating strokes of a file; from the peculiarity of the sound emanation we can actually determine whether the file employed is coarse or fine. From the peculiar quality of sound produced the ear can determine the tool or implement used. In the shop of a goldsmith, a workman is polishing a gold ring with a burnisher. The polishing is effected by a rubbing motion, and not by a series of blows: consequently no sound is heard. This calls to mind the action of the violinist, who rubs resin on the hair of his bow, in order that the friction between it and the violin strings may be intermittent, or produced in beats. In order that we may hear some other sounds save those produced by metal, let us visit a carpenter's shop. The ear again unerringly discriminates the sound produced by planing, sawing, filing, &c., and detects that wood not iron is the material. The reason for this difference in the sound produced is to be found in the fact that the substances of which wood and metal are composed differ. In the distance we hear men hammering on a boiler: here we recognise from the resonance that it emanates from a boiler. In short, the ear can discriminate with such nicety the multitude of sounds that one is mostly inclined to say that the ear can see with the auditory nerve as well as can the eye with the optic nerve. Sound is either dull or clear, just as the musical sounds range from the deepest bass to the highest treble. In all conditions the ear can distinguish the material producing the sound.

My instructor had attached to his cane a small hammer, with which he rapped upon any piece of timber he intended to purchase, in order to judge its condition. By long practice and experience he could tell to a certainty whether a piece of timber were in good or bad condition; and, if in bad condition, the extent of unsoundness existing in it. Applying the foregoing to musical instruments, we will be enabled forthwith to perceive what instrument is being played, first, by the sound colour which results from the material composing the instrument; secondly, by the sound colour caused by the shape of the resonant body; and thirdly, by the sound colour resulting from the peculiar manner of producing the sounds by means of mechanical appliances. It would require too much space were we to describe all the individual peculiarities of the different instruments; therefore attention may here be called to the fact that the ear distinguishes not only the manner in which a body is set in motion but also the form assumed by this motion. We can clearly perceive the difference in a tone produced by the blow of a hammer on the strings of a piano and that caused by drawing a bow over the strings of a violin. This difference lies chiefly in the fact that the tone produced by the impact of the hammer against the strings is of short duration, whereas the contact of the bow with the strings is of longer duration. The sound also indicates whether the bow is drawn continuously over the strings, or applied in a halting, springy manner. A quick, good ear will also discriminate between an up or down stroke of the bow, or readily detect the harmonics *(flageolets)*, sounds which are produced by a peculiar stopping of the strings. Thus we perceive that every peculiarity in the treatment of the tone producing body, together with the peculiar action of the mechanical apparatus upon it, is recognised and judged with nicety. It is indeed incredible with what acuteness the ear detects these peculiarities. With what admiration have we listened to the wonderfully shaded and expressive tones drawn from the piano by a capable pianist, whose clever manipulation of the keys has set in motion the complex mechanism of the instrument! There can be no doubt that the ear experiences a real sense of feeling, by which it seems to be brought in touch with the tone producer, just as by the sense of touch we can discriminate objects. Thus, if two bodies collide, we not only hear the blow but we also feel the effect produced; we not only hear the sound of a cry of pain or distress, but our feelings also are acted upon. The art of imparting to others by means of musical or theatrical representations the feelings which the actor wishes to pourtray is based upon this peculiar sense of sympathy. It is a fact that the musician does not display his art solely by producing tones of a certain difference in pitch, but rather by the character which he imparts to his playing. The intervals in their many changes may afford a pleasing effect of tone colour, but it is the effect of the sound produced by the beats themselves which arouses any real sympathy for that which we hear; and in consequence tone character has become an important and weighty factor in music. The tone character of a musical instrument determines its value.

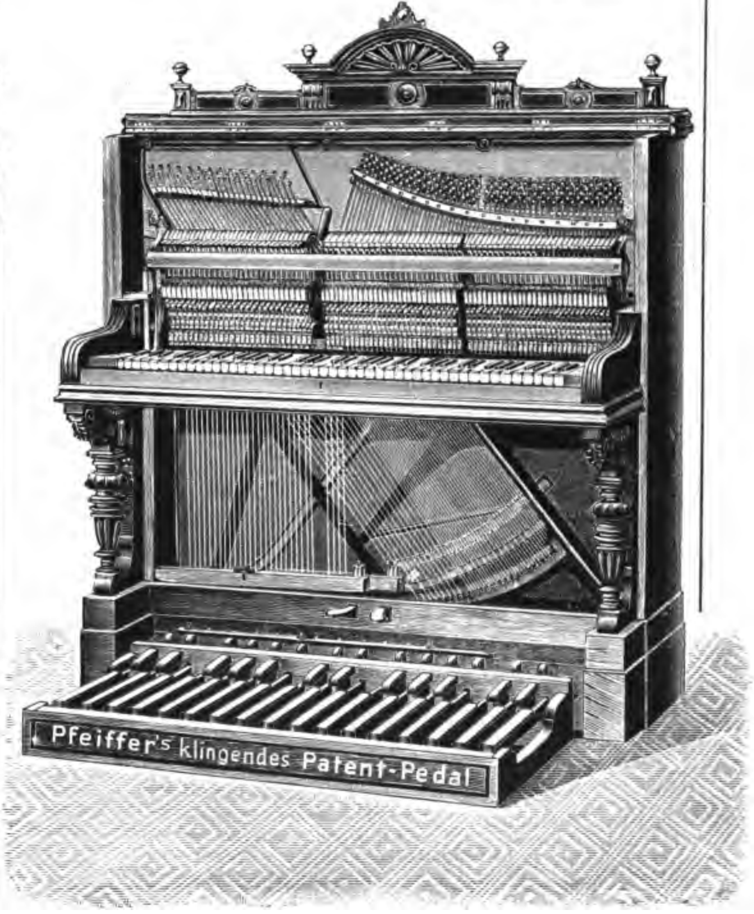
With regard to a piano, it is especially easy to describe the distinction between sound and pitch. Two men, a tuner and a tone regulator, are required in regulating the tone of a piano. The tuner attends exclusively to the pitch, and endeavours to regulate the intervals of various and similar tones through the simultaneous occurrence of the beats. For example, the beats of the three strings producing one tone must synchronise, then will the three strings harmonise and their intervals commensurate. The "toner" occupies himself solely with the quality or the sound of the tone. It does not deteriorate from the proficiency of a tuner if he is not a good tone regulator, nor must the toner necessarily be a good tuner. The tuner, devoting himself to intervals, does not concern himself about the sound or the material used; that is the province of the tone regulator. The felt covering of the hammer heads, by special and proper treatment, causes the tone to be clear or dull, harsh or soft. It is not only the felt, however, but also the stem of the hammer and other portions of the mechanism—yes, even the instrument itself—which by their special properties affect the tone. Moreover, these parts need not necessarily come in immediate contact with the strings to produce an effect on the tone; for the instrument, considered in its entirety, is one sound producing body. Although the sound of a tone may be considerably changed by altering the tension of the strings in a piano, which is done by rising or lowering the pitch, it is evident that, as the tension of the strings works directly on the matter composing them, it is the material and not the pitch which causes a change of sound.

From all this we have adequately learnt that sound and pitch are two essentially different properties of tone. The property of sound depends directly on the sound producing body. Pitch, however, does not depend in any way upon the body: it is caused by the nature of the ear. Hence it is physically impossible to produce any special tone character by combining different degrees of pitch. Whenever an attempt has been made to demonstrate that certain differences of pitch form a distinctive or peculiar tone character, it has resulted in confounding tone colour and sound colour. Referring to Tyndall's "Sound" (p. 144) we find: "Higher tones mingle with the fundamental one, and it is their intermixture which determines what, for want of a better term, we call the quality of the sound. The French call it *timbre*, and the Germans call it *Klangfarbe*. It is this union of high and low tones that enables us to distinguish one musical instrument from another. A clarionet and a violin, for example, though tuned to the same fundamental note, are not confounded. The auxiliary tones of the one are different from those of the other; and these latter tones, uniting themselves to the fundamental tones of the two instruments, destroy the identity of the sounds." It is a case of adding unequals to equals: the sums are unequal. On page 149 in the German edition of Tyndall, we find clearly expressed that "the addition of these overtones to the fundamental tone determines the *timbre* or quality of tone, or as we will call it—the sound colour." No doubt Tyndall here endeavours to determine the character of the tone from its pitch. According to his theory we are unable to distinguish between the notes of a piano and those of a zither, because the strings of each possess the same overtones. Here we add equals to equals and the sums are equal. Not only the strings of a zither but also those of the violin possess the same overtones as the piano strings: hence we find three different instruments which cannot be distinguished. Bearing in mind that the sounding-boards are made from the same material, we distinguish the three mentioned instruments one from the other by the characteristic qualities of their respective strings. If the string of a piano be manipulated in zither style, it is an undeniable fact that it is difficult to distinguish between the tones of the two instruments. This resemblance, however, does not arise, as Tyndall imagines, from the similarity of the overtones, but because the metal strings are identical in their composition. When the violin string is made to sound by being plucked, we readily perceive the difference between the metal and the catgut string.

Tyndall asserts that overtones are indispensable to the musical character of tones. He says (German edit., p. 363): "Pure tones without overtones would be like pure water,—flat and dull. The tones, for example, of wide stopped organ pipes, are almost perfectly pure, for the tendency to subdivide is here so feeble that the overtones of the pipe hardly come into play. But the tones of such pipes, though mellow, would soon weary us; they are without force or character, and would not satisfy the demand of the ear for brightness and energy. In fact, a good musical "clang" requires the presence of several of the first overtones. So much are these felt to be a necessity that it is usual to associate, with the deeper pipes of the organ, shorter pipes which yield the harmonic tones of the first named pipes. Where the vibrating body itself is incapable of furnishing the overtones (harmonics), they are supplied from external sources." Although we are convinced that overtones do not determine the character of a tone, still there are peculiar phenomena about sounding bodies which might shake the conviction. For example, should we strike the prongs of a tuning fork with a small bar of steel, we discover that the fundamental tone of the fork almost becomes inaudible, and that conjointly with the metallic sound we distinctly hear the auxiliary tone of the fork. We notice, but in a lesser degree, that when a piano string is struck with a very hard felt hammer, there is with the metallic sound a confusion of overtones. The metallic sound of the string arises from the hard beats which the strings give; for through the hard stroke of the hammer the material of the string is strongly agitated. It is therefore evident that, when the beats of the string are violent, the tones resulting from such beats (they are the overtones) must become prominently and distinctly audible. Nothing is more distressing than to listen to a piano that possesses this quality; it is not the metallic sound of the string that is so unpleasant, but solely the overtones. For this reason we seek to weaken the beats of the string to a certain degree: this point is gained if, in tone regulating, the felt hammer head is pricked with needles to render it softer, thereby restraining the force of the blow upon the strings. By this operation we unfortunately lose a part of the metallic sound of the strings, and this loss is greater in proportion as the arrangement of the strings renders the overtones especially prominent. In instruments so constructed, it frequently necessitates the felt covering of the hammer head to be so soft that the clear metallic tone is completely lost, and in its stead we hear a dull, colourless tone which renders the instrument utterly devoid of a fresh, ringing quality. Hence a perfect arrangement of the strings and of the sounding-board, &c., permits the use of a hard felt hammer head, which, again, ensures a clear, crisp, metallic sound, without any serious admixture of overtones. Every piano maker will, from his own experience, recognise and confirm the truth of these remarks, and many of my readers will add to them. Later on we shall have occasion to enquire more particularly into the causes and effects of the different modes of arranging strings in a piano. Thus we see that we refute the erroneous assertion given in the German edition of Tyndall's "Sound" by endeavouring not to retain the overtones (regarding them in the light of unpleasant nuisances) and by seeking to bring forth only the pure sound of the tone producing·body.

I have already stated that the value of musical instruments depends on their sound. On the organ the addition of an upper fifth to the fundamental tone produces a pleasing effect: not so with the piano. Again, to contradict Tyndall's assertion that "pure tone without overtones is dull and flat," be it said that the pure production of a tone enhances its musical value. Men of renown state that at least five of the first overtones, harmonising with the fundamental one, are requisite to obtain a good musical tone from a string; others point out the fact that, for instance, Appunn's Victoria bells in the Nicolai Kirche at Frankfurt a/M., sound in their fundamental tone; and, contrary to other bells, each separate one has but a single harmonic overtone that produces a sound character which, when two or more of these bells sound together, gives to the unity of sound something wonderfully musical. The flute has but one harmonic overtone; but surely no one will mistake its tone for that of a bell.

Tyndall labours under a great mistake when, as in the German edition, he says: "If we could tune all instruments to the same fundamental tone, dispensing with all overtones, we could not distinguish one from another." In music the sound colours of the various instruments are brought to use, and in this respect orchestral music takes the lead. Just as the changing tones held in a certain rhythm affect us pleasantly, so the change or play of the tone character touches us and lends an odd charm to the music. No one imagines that this charm springs from overtones! The materials of which the various instruments are constructed, their many and varying forms, and the different modes by which the instruments are made to sound constitute their character.


Pfeiffer's klingendes Patent-Pedal

Chapter III.

Tone colour.

Tuning directions.

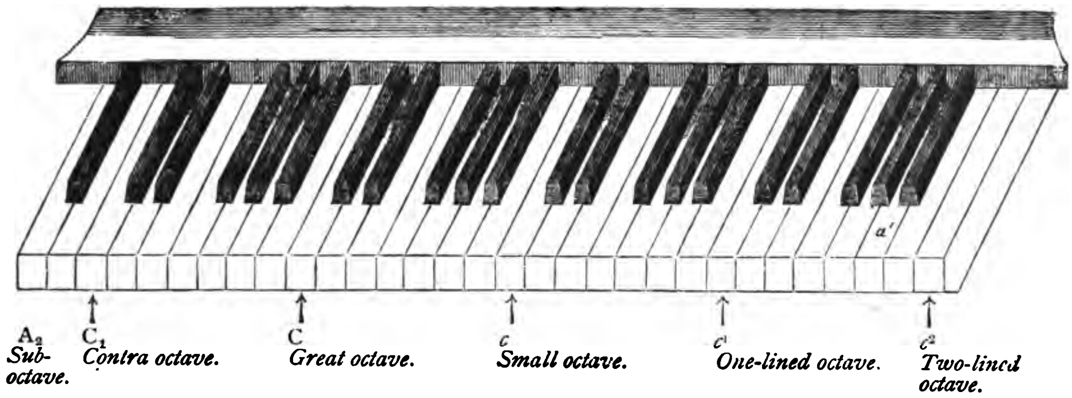
There are seven fundamental tone colours in music. As early as the year 1666, after the established recognition of these seven music tones, Sir Isaac Newton distinguished seven tones in light. These light tones are red, orange, yellow, green, blue, indigo, and violet; of these red is the lowest and violet the highest light tone. In music the seven tone colours are prime (tonic), second (supertonic), third (mediant), fourth (subdominant), fifth (dominant), sixth (submediant), seventh (leading tone) eighth (octave), the latter being a repetition of the prime. The eye discriminates only a single octave of light colour, whereas the ordinary ear distinguishes at least eight octaves of tone colours; a highly educated and well trained ear can extend the limit to eleven. In like manner as can a combination of light colours produce a harmonious or incongruous presentment to the eye, so can a combination of diverse tone colours present a concord or discord to the ear. A combination of two tones can produce either a consonance or a dissonance. Two tones are consonant when they cause a harmonious, satisfying, restful combination of sounds. A prime and its third sounded simultaneously are called a third, and are an imperfect consonant; three notes—i.e., prime, third, and fifth—form a consonant chord known as a triad. A chord composed of four notes within the octave must form a dissonance,—i.e., prime, third, fifth, and seventh; in order to convert the dissonance into a concord, we substitute the octave in lieu of the interval of the seventh. The seven tone colours form the normal diatonic major scale to which the octave tone is added as a closing. The degrees are named respectively C D E F G A B *c*, and this order is repeated throughout the series of octaves; each octave, for convenience in speaking or writing, bears a distinguishing name. The order of the octaves from the lowest to the highest is as follows: suboctave, contra octave, great, small, one lined, two lined, three lined, four lined, five lined, &c. For exemplification, see Fig. 1 (next page).

The key-board of the piano in general use at the present day begins with sub A and ends with five lined *c*. The key-board, however, may be extended at will, until the limit of hearing is reached. There are church organs whose lowest tone is sub C, the pipe for this tone being $10^{1}/_{2}$ mètres long; the highest tone is seven lined *c*, and its pipe is 13 millimètres long. Such an organ embraces in its compass almost the extreme limits of our hearing power. Each octave begins with C, and each note within the octave has the same prefix as the prime or keynote, until the next C is reached, and so on. To distinguish the different octaves, certain marks of abbreviation are used, either lines or figures being affixed to the seven tone colours. Thus:—

C_2	C_1	C	*c*	c^1	c^2	c^3	c^4
Sub.	Contra.	Great.	Small.	One-lined.	Two-lined.	Three-lined.	Four-lined. &c.

We may regard each note as a fundamental by making it a tonic or keynote: in this manner we can distinguish one scale from another. Thus, in the scale of C major, C is the tonic; in the scale of G, G is the tonic, &c. There are fundamental common chords in each scale. Take, for instance, the scale of C major. C E G forms the chord of the tonic, G B D the chord of the dominant, F A C the chord of the subdominant. We may, however, take G B D as the chord of the tonic in the scale of G. Then the chord of the dominant would be founded on D; F would, however, be a semitone too low to form a major third, so it must be raised the required semitone. Here we encounter a new note, which has not been mentioned in

Fig. 1.


a'
A_2
Sub-octave.
C_1
Contra octave.
C
Great octave.
c
Small octave.
c^1
One-lined octave.
c^2
Two-lined octave.

our musical alphabet; we therefore place it next to F and call it F sharp (F♯), and now find that our chord of the dominant is composed of D F♯ A. In this way the black keys F♯, G♯, A♯, C♯, D♯, were inserted in the piano key-board. Thus one octave consists of twelve keys which produce all the notes of the chromatic scale.

The chromatic scale is a succession of semitones only; and, using each successive semitone as a fundamental or keynote, we can form twelve major and twelve minor scales. To preserve the same succession of intervals in all diatonic scales, sharps and flats are introduced, according to the progression of each scale. The sharp (♯) is a character placed before a note, raising it a semitone; the flat (♭) is a character placed before a note, lowering it a semitone. Of course, only one key of the key-board is used for the purpose of raising one note or for lowering its immediate successor. Thus C♯ and D♭ are sounded by striking the same key, E♯ by striking the F key, F♭ by striking the E key; and so on.

The piano is not a perfect instrument, and cannot therefore with its key-board give with exactitude the proper difference between a sharp and a flat: hence this shortcoming must be obviated in the process of tuning. The interpolated tones are associated with the seven fundamental tones thus: taking C as tonic, a progression to C♯ is termed an augmented prime, to D a major second, to D♭ a minor second, to D♯ an augmented second, to E a major third, to E♭ a minor third, from C♯ to E♭ a diminished third, from C to F a perfect fourth, to F♯ an augmented fourth, from C♯ to F♮ a diminished fourth, from C to G a perfect fifth, to G♯ an augmented fifth, from C♯ to G♮ a diminished fifth; and so forth. From C to C is a perfect octave, C♯ to C♮ is a diminished octave. Notes in the octave above that of the tonic alter their interval names according to the relation in which they stand to the fundamental note. Thus, the second of the higher octave is the ninth to the fundamental, the third of the octave becomes the tenth of the fundamental tonic, and so on until the double octave is reached. The major triad C E G contains a major third, and is distinguished from the minor triad C E♭ G which contains a minor third.

These constitute the essential points with which a piano maker must be conversant. The practical piano maker does not require a further knowledge of harmony: he pays attention to the tone colour of his instrument only.

Music teaches us which combinations of tones harmonise and which do not, and it discriminates between consonances and dissonance. It is universally known that the pianoforte is not tuned perfectly true, but that the intervals are tempered. Each semitone in the progression must bear a uniform relation one to the other. Tuning by semitones would be very difficult, if not impracticable: hence all tuners use the well known "quint circle," or progression of fifths. Tuning the fifth or dominant with the tonic is to be preferred to any other interval: for instance, to the third, because prime and fifth form one of the best consonances, and the difference between the perfect and tempered fifth is smaller than between other intervals in the octave. All fifths progressing upward should sound a trifle flat; all thirds progressing upward should sound a trifle sharp. The octave must be perfectly true; but as they ascend they should sound to the ear rather a little sharp than flat. Only a practised ear can determine the proper deviations from the true pitch. To test if the piano has been properly tuned, strike the different chords, observing if all the different tones accord. A beginner is urgently advised to seek instruction in tuning from a practical and experienced tuner, and not from a musician. A musician recognises and judges the value of a tone from its sound in conjunction with other tones, its tone colour, or corresponding rhythm; the ear of a tuner marks the beats of a note in order to be able to measure the intervals and determine a certain pitch. A musician without experience and practice in the measurement of intervals is not capable of tuning a piano. There is a great difference between recognising the pitch of a tone through its tone colour and determining the pitch through measurement of the intervals. Compared to the musician, the tuner makes a poor show in recognising the tone colour of notes.

Here follow the succession of notes which must be struck together in tuning, and which when taken together form the "circle of fifths" (quint circle). The first letter within each set of brackets denotes the tone tuned, while the second one represents the tone to be tuned according to the first named. Begin by tuning A^1 to international pitch, and then proceed:—

[A^1-A] [A-E^1] [E^1-E] [E-B] [B-$F\sharp^1$] [$F\sharp^1$-F♯] [F♯-$C\sharp^1$] [$C\sharp^1$-$G\sharp^1$]
[$G\sharp^1$-G♯] [G♯-$D\sharp^1$] [$D\sharp^1$-D♯] [D♯-A♯] [A♯-F^1] [F^1-F] [F-C^1]
[C^1-G^1] [G^1-G] (G-D^1] [D^1-A^1]

Having tuned the fourth "fifth" — namely, $C\sharp^1$ — strike the A major chord, composed of A $C\sharp^1$ E^1 A^1, and you can measure or judge the correctness of the pitch of the fifths already tuned. The third of this chord, $C\sharp^1$, should be a little sharp in pitch, only enough however to agree with the rest of the chord. Some tuners, before commencing the series of fifths, begin by taking the third to A [A-$C\sharp^1$], then down two fifths,—thus, [$C\sharp^1$-F♯] [F♯-$F\sharp^1$] [$F\sharp^1$-B]. Then follow two fifths upward from A,—thus, [A-E^1] [E^1-E] [E-B]. At B the result of the equalisation is reached: an error is easily detected and corrected without loss of time.

After the first four "fifths" of the circle are properly tuned, one has, so to speak, a guide by which to tune the remainder; that is to say, each new fifth may now be taken as third in a chord of which the tonic and fifth have been tuned. The temperament being correct, tune the bass downward in octaves and the treble upward in octaves. Do not invert this order of procedure, because, through the tension of the strings on the ends of the instrument, the straining of the strings on one side causes a sympathetic action of the strings on the other side; and, as the treble notes are much more susceptible and sensitive to the least alteration in tension than are the bass notes, it is found to be most advantageous to tune in the manner pointed out.

Chapter IV.

Relative proportions of tone.

We discriminate the pitch of different notes by the duration of the intervals between the beats given by a sounding body. The duration of the intervals between the beats is measured by or in the fraction of a second of time. For instance, the tone of a^1 has 435 beats per second; as these 435 beats must be equally divided, it follows that the intervals between the beats must be $\frac{1}{435}$ of a second's duration. The intervals of a tone having double this number of beats naturally endure only half as long. Hence we assert that the duration of the intervals stands in direct inverse ratio to the number of beats. The duration of intervals may also be represented by long measure (or measure of length). For instance, whether the pitch of a tone be high or low, its rate of speed through the air, at a temperature 32° F. (freezing point), is computed to be about 333 mètres (= 366 yards) per second. If a tone has 333 beats per second, it is clearly evident that, when the second beat occurs, the first has travelled one mètre from its starting point, and consequently the subsequent beats follow each other in the same proportions, — a mètre apart. A tone having double the number of beats can have the distance between them only half as great, or equal to half a mètre.

The law derived from these facts is not only applicable to columns of air (say, for instance, in organ pipes) but also to sounding musical strings. Thus, if we divide a vibrating piano string into two equal parts, we immediately hear the octave of the fundamental tone which would have been produced had the entire string been allowed to vibrate. From this fact we positively assert that a string of half the length gives double the number of beats; consequently, the duration of the intervals decreases as the length of the string decreases, and *vice versâ.*

The length of a string divided in the middle is proportioned to the entire length as 2 : 1; so also is the tone interval of the octave proportioned to that of the prime or tonic as 2 : 1. Divide the string into three equal parts and the fifth of the octave is obtained. One third of the string produces the twelfth, two thirds the lower octave of this twelfth (or the fifth of the prime). Proceeding in this way, we find that three fourths of a string give us the fourth and four fifths the third. By shortening the string one sixth, one seventh, or one eighth, we produce tones that cannot be expressed in our tonal system; but, remarkably, we obtain by shortening the string one ninth the second of our system from the remaining eight ninths. The sixth is obtained from three fifths of the entire length, the seventh or leading tone from eight fifteenths.

Since the lengths here given stand in proportion to the entire string's length, the tone intervals of the tones produced by these lengths stand in proportion to the tone interval of the prime. Arranging systematically the proportional numbers, we gain a clear view of, not alone the proportions of string's length but also of the proportions of tone intervals.

Prime.	Second.	Third.	Fourth.	Fifth.	Sixth.	Seventh.	Octave.
1	$\frac{8}{9}$	$\frac{4}{5}$	$\frac{3}{4}$	$\frac{2}{3}$	$\frac{3}{5}$	$\frac{8}{15}$	$\frac{1}{2}$

The proportion which the number of beats of these tones stands to the prime is as follows. Prime: second = 8 : 9,—i.e., the prime has eight beats during the same time in which the second has nine; prime : third = 4 : 5; prime : fourth = 3 : 4; &c. The proportion of the common chord is prime : third : fifth = 4 : 5 : 6, showing that the prime has four beats whilst the third and fifth have five and six respectively; likewise, that the fourth beat of the prime, the fifth beat of the third, and the sixth beat of the fifth occur simultaneously. The proportion of the six-four chord is prime : fourth : sixth = 3 : 4 : 5. The tones of these chords are consonant with their respective chords, and this we can see from the close position of the figures in the ratio.

Let us now take a chord containing a dissonance, — for instance, by changing the fourth in the last named chord to a third. The proportional numbers now come further apart:—thus, prime : third : sixth = 12 : 15 : 20, showing that the respective beats only occur simultaneously when the prime has its twelfth beat. In a subsequent chapter we shall see how the irregular intervals of this proportion disturb the rhythmic movement of the chord, causing the ear to be sensible of a discord produced by these tones.

In order to obtain the relative proportions between each note and its successor, we divide two successive numbers or parts into each other, with the following result. Prime : second = 8 : 9; second : third = 9 : 10; third : fourth = 15 : 16; fourth : fifth = 8 : 9; fifth : sixth = 9 : 10; sixth : seventh = 8 : 9; seventh : octave = 15 : 16.

As soon as we ascertain the number of beats of any given tone, we can build up a tonal system of wide range by following the above stated proportions, and can unerringly reckon and state precisely the number of beats of every tone in the system. One lined *a* (a^1) is to-day taken as the normal tone, or standard of pitch. The following table, quoted from Levi K. Fuller's circular (dated March, 1891), shows the different pitch given this tone by conductors and composers of various periods.

Pitches given to a^1 by some early composers.

a^1 422·5.—Händel (1751).
a^1 421·3.—Mozart (1780).
a^1 455·1.—Wagner Festival, London (1877).
a^1 454·1.—Crystal Palace, London (1878).

Modern orchestral and medium church pitch.

a^1 439·4.—Dresden Opera (1878).
a^1 437· —Toulouse Conservatory (1859).
a^1 443· —Stuttgart Opera (1859).
a^1 443·1.—Boulogne (1869).
a^1 443·2.—St. Stephen's Organ, Vienna (1878).
a^1 448·1.—Munich Opera (1859).
a^1 451·9.—British Army Regulations (1878).

This may suffice to show how essential it was, and still is, to establish an international, unchangeable, normal tone or standard of pitch, for the benefit of music in general, in all countries, for all orchestras and for all instrument makers.

For many years the standard pitch in France was a^1 870 single vibrations, or 435 double vibrations. This pitch was adopted by nearly all other countries. By a single vibration we understand the upward movement of the piano string from its line of rest; a double vibration consists of the upward and downward undulation of the string, or of two single vibrations. Only in France, however, is this discrimination made; all other countries understand the word vibration to signify always double vibrations.

Although a^1 435 is a very suitable, gratifying pitch for musicians (who reckon only by pitch, and not by numbers as natural philosophers do), we will allow the standard of the latter a^1 440 to be the one by which we establish a tonal system, as it materially facilitates our calculations. The following table, allowing a^1 440 beats, shows at a glance the relative proportions of the tones in a diatonic scale.

	1 Tonic 1 ×	$\frac{9}{8}$ Second $\frac{9}{8}$ ×	$\frac{5}{4}$ Third $\frac{10}{9}$ ×	$\frac{4}{3}$ Fourth $\frac{16}{15}$ ×	$\frac{2}{3}$ Fifth $\frac{9}{8}$ ×	$\frac{5}{3}$ Sixth $\frac{10}{9}$ ×	$\frac{15}{18}$ Seventh $\frac{9}{8}$ ×	2 Octave $\frac{16}{15}$
Sub octave	C_2 16·5	D_2 18·5625	E_3 20·625	F_2 22	G_2 24·75	A_2 27·5	B_2 30·9375	
Contra ,,	C_1 33	D_1 37·125	E_1 41·25	F_1 44	G_1 49·5	A_1 55	B_1 61·875	
Great ,,	C 66	D 74·25	E 82·5	F 88	G 99	A 110	B 123·75	
Small ,,	*c* 132	*d* 148·5	*e* 165	*f* 176	*g* 198	*a* 220	*b* 247·5	
One lined ,,	c^1 264	d^1 297	e^1 330	f^1 352	g^1 398	a^1 440	b^1 495	
Two ,, ,,	c^2 528	d^2 594	e^2 660	f^2 704	g^2 792	a^2 880	b^2 990	
Three ,, ,,	c^3 1056	d^3 1188	e^3 1320	f^3 1408	g^3 1584	a^3 1760	b^3 1980	
Four ,, ,,	c^4 2112	d^4 2376	e^4 2640	f^4 2816	g^4 3168	a^4 3520	b^4 3960	
Five ,, ,,	c^5 4224	d^5 4752	e^5 5280	f^5 5632	g^5 6336	a^5 7040	b^5 7920	

Considering the proportional numbers for the tone intervals from tone to tone (as in the table), we find a threefold relation existing; we recognize that the greatest proportional number $\frac{8}{9}$ belongs to a great full tone, the smaller $\frac{9}{10}$ to a lesser full tone, and the smallest proportional number $\frac{15}{16}$ makes the interval of a half tone.

Thus far we have considered the intervals of the diatonic scale. We will now turn our attention to the intervals of the chromatic scale. Taking *C* as the fundamental, a progression of a half tone to *C♯* forms a chromatic semitone; whereas in the C major scale the progression from *E* to *F* forms a diatonic semitone. The relative proportion of a diatonic semitone is $\frac{15}{16}$, and by calculation we determine a chromatic semitone to be $\frac{128}{135}$. For instance, C has 66 beats; therefore D as a greater full tone must have $66 \times \frac{9}{8} = 74{\cdot}25$ beats. From C to C♯ being a chromatic semitone in the scale of C major, C♯ has $66 \times \frac{135}{128} = 69{\cdot}609375$ beats. C♯ is also the seventh or leading tone in the scale of D major, and in this position it bears the relative proportion of a diatonic semitone: hence, multiplying $69{\cdot}609375 \times \frac{16}{15}$, we find a product $= 74{\cdot}25$. If we take the scale of A major, we find that the tonic A has 55 beats, and the major third C♯ has $55 \times \frac{5}{4} = 68{\cdot}75$ beats; this shows that C♯ considered as a major third is somewhat deeper than C♯ the chromatic semitone. We can find such discrepancies in great numbers, depending entirely upon the tone selected as fundamental or keynote upon which to construct a tonal system or in accordance with which to change any other system. It is very evident that the existence of a greater and a lesser full tone must necessitate difference of relative proportions. For instance, when we have tuned the scale of C major perfectly true, we shall have D immediately following the keynote as greater full tone; whereas, if we play the scale of D major, a lesser full tone follows the tonic, and in order to have this scale perfectly true we must tune again the other tones of the scale in relative proportion to the fundamental tone.

The piano being an instrument of limited expression of tone, it is of course impossible to make any distinction between a greater or lesser full tone, or between a diatonic and a chromatic semitone. Having somewhat befriended ourselves with the untrue chords which are thus caused, we might have the temerity to assert that it may be possible to produce an augmented and a diminished tone by striking the same key. To exemplify: C♯ and D♭ are two tones distinguishable each from the other by the proportions of their intervals. If C be regarded as leading tone to D♭, then a diatonic interval separates them; as C has 66 beats, D♭ has 66 × $\frac{16}{15}$ = 70·4 beats. We have proved, however, that C♯ as a chromatic semitone above C has only 69·609375 beats. However, the equable and well tempered tuning of our pianos hinders the perception of the extent of such differences in tone proportions, and by smoothing over inequalities that exist in the various scales it renders them very endurable. In the explanation of tempered tuning, I shall give the intervals in measures of length, thereby rendering my meaning clear to piano makers. The advantage gained by this method is that, as the proportions of the intervals of the tones correspond exactly to the lengths of the strings producing the tones, the measure of the intervals may be transferred to strings, thus allowing the manufacturer to render the different relative proportions of the tones audible.

In the following table, (c) is supposed to represent any chosen fundamental tone; the pitch of (c) has therefore been so chosen that it will allow any calculations thereon to be made with ease. This (*c*) has 333 beats per second; and, as the speed of sound travelling through the air equals 333 mètres per second, the tone interval must be one mètre, or 1000 millimètres, or 10,000 lines; the mètre rod is here the measure of unity. If, therefore, we stretch a string upon a monochord, the sounding portion of the string being one mètre long, this length will give the fundamental tone; it is a matter of indifference what pitch the tone has. By means of the moveable bridge of the monochord, we can render audible the difference between a true and a tempered fifth. We find the true fifth by adjusting the bridge in such a manner that the string is shortened one third of its length; should we sound the string when its length is 667·423 millimètres, we shall find the tempered fifth. Again, if we stretch three strings on the monochord, each string being one mètre long and of course in unison, and then sound the first string in its entirety, the second at two thirds its length, the third with a length of 667·423 millimètres, we naturally hear plainly the difference between a true and a tempered fifth, and we feel the effect arising therefrom. In this manner we can construct an instrument on which all the intervals can be mathematically calculated. The proportional number of a tempered fifth reckoned with logarithms is 1·4983. If we try to find the greatness of the intervals of the tones in a circle of fifths (quint-circle) by means of this proportional number, we find the following:—

c = 1000·000 millimètre.
g = 667·423 ,,
G = 1334·846 ,,
d = 890·907 ,,
a = 594·612 ,,
A = 1189·224 ,,
e = 793 722 ,,
E = 1587.444 ,,
B = 1059·496 ,,
f♯ = 707·132 ,,
F♯ = 1414·264 millimètre.
c♯ = 943·912 ,,
g♯ = 629.987 ,,
G♯ = 1259·974 ,,
d♯ = 840·935 ,,
D♯ = 1681·870 ,,
A♯ = 1122·520 ,,
f = 749·195 ,,
c^1 = 500·030 ,,
c = 1000·060 ,,

The circle of fifths closes with (*c*), our fundamental note, and we find that the tone (*c*) is as much too low as would be caused by the addition of $\frac{3}{50}$ millimètre to the length of a string one mètre long. If we seek to ascertain how much the tempered tuning differs from the true in the major chord *c e g*, we find that (*c*) calculated with 1000 millimètres string's length, the tempered third (*e*) with 793·722 millimètres string's length, and the true third requires a length of 1000 ÷ $\frac{5}{4}$ = 800 millimètres. If, therefore, we have a string 800 millimètres long giving the note (*e*), the tempered (*e*) in the chord would be as much too high as the shortening of the string by 6·278 millimètres would represent. The true fifth requires a string 1000 ÷ $\frac{3}{2}$ = 666·666 millimètres long; the tempered fifth requires one 667·423 millimètres long. Hence the difference between a true and a tempered fifth amounts to an addition of 0·757 millimètres to a string 666·666 millimètres long.

The number of beats of the tempered tones as compared with their prime may be found by using the following proportional numbers, which have been calculated by logarithms:—

c = 1·00000
c♯ or *d*♭ = 1·05946
d = 1·12246
d♯ or *e*♭ = 1·18920
e = 1·25992
f = 1·33484
f♯ or *g*♭ = 1·41421
g = 1·49830
g♯ or *a*♭ = 1·58740
a = 1·68180
a♯ or *b*♭ = 1·78180
b = 1·88774
c^1 = 2·00000

The origin of these numbers may be found through the following:— The proportion of intervals of prime to octave stands as 1 : 2. Within this proportion there lie twelve tone intervals for the chromatic scale so that, if these tone intervals are to have an exact geometric proportion from half tone to half tone, a number must be found which, multiplied twelve times by itself produces the number 2. This number 12 2 carried out to five decimal points is 1·05946. Multiplying this number twelve times by itself the above results are obtained. According to these figures, in tempered tuning, the number of beats may be found for each tone; however, I prefer to give a table according to the specifications of the distinguished Parisian, Dr. Rudolph Koenig. *(See page 45.)*

Should we now institute a comparison between the number of beats in the tones of the major chord *c e g*, we should find that, taking *c* as fundamental with 1000 beats, the pure or true third will have $1000 \times \frac{5}{4} = 1250$ beats; the tempered third will have 1000 × 1·25992 = 1259·92 beats, nearly ten beats more than the true third. The true fifth will have $1000 \times \frac{3}{2} = 1500$ beats; the tempered fifth will have 1000 × 1·49830 = 1498·30 beats, or two beats less than the true fifth. It is easily perceived that *c*♯ and *d*♭, for instance, have the same number of beats in tempered tuning, because they are produced by the same set of strings. The same is true of *d*♯ and *e*♭, &c. In tempered tuning some of the intervals must suffer more or less in their purity.

Dr. Oscar Paul designates tempered tuning as a very endurable evil, and reminds us that our organs of hearing are accustomed to much greater discrepancies in concord, meaning thereby that tempered tuning approaches much nearer to the pure tone than do the tones of many pianos to which we listen in concerts and deem quite endurable. We quite agree with this view of the subject. With very little trouble anyone can produce a well tempered chord beside a true chord and discover that the tempered chord does not produce on our organs of hearing any disturbing effect. I can assure you that the pleasing and peculiar effect produced upon our ear by the sound of chords is more the result of the tone character of the instrument than from discrimination between the tempered and true tuning. However well a piano may be tuned, if of a bad tone character, it cannot produce a good tone. On the other hand, a piano with a good tone character, when well tuned, will always give forth agreeable and pleasing sounds. This fact is particularly worthy of mention, as some piano makers are trying to introduce an enharmonic scale for the piano. Such a scale is a veritable monstrosity so far as practical use goes. Be careful that the instrument has an agreeable sound colour and will remain in tune; then all such other innovations and alterations in the mode of tuning are superfluous.

Scale of tempered tuning.

(Normal $a^1 = 435$ beats.)

Sub octave	C 16·166	C♯ 17·127	D 18·145	D♯ 19·225	E 20·363	F 21·579	F♯ 22·862	G 24·221	G♯ 25·662	A 27·188	A♯ 28·804	B 30·517
Contra ,,	C 32·331	C♯ 34·254	D 36·290	D♯ 38·449	E 40·735	F 43·157	F♯ 45·723	G 48·442	G♯ 51·323	A 54.375	A♯ 57·608	B 61.033
Large ,,	C 64·663	C♯ 68·508	D 72·581	D♯ 76·898	E 81·470	F 86·314	F♯ 91·447	G 96·885	G♯ 102·646	A 108·750	A♯ 115·216	B 122·067
Small ,,	*c* 129·326	*c*♯ 137·016	*d* 145·163	*d*♯ 153·796	*e* 162·960	*f* 172·629	*f*♯ 182·895	*g* 193·770	*g*♯ 205 292	*a* 217·500	*a*♯ 230·433	*b* 244·135
One lined ,,	*c* 258·652	*c*♯ 274·033	*d* 290·327	*d*♯ 307·592	*e* 325·881	*f* 345·259	*f*♯ 365·790	*g* 387·541	*g*♯ 410·585	*a* 435	*a*♯ 460·866	*b* 488·271
Two ,, ,,	*c* 517·305	*c*♯ 548·066	*d* 580·655	*d*♯ 615·183	*e* 651·763	*f* 690·519	*f*♯ 731·580	*g* 775·082	*g*♯ 821·171	*a* 870·000	*a*♯ 921·733	*b* 976·542
Three ,, ,,	*c* 1034·610	*c*♯ 1096·132	*d* 1161·310	*d*♯ 1230·366	*e* 1303·526	*f* 1381·038	*f*♯ 1463·160	*g* 1550·164	*g*♯ 1642·342	*a* 1740·000	*a*♯ 1843·466	*b* 1953·084
Four ,, ,,	*c* 2069·220	*c*♯ 2192.264	*d* 2322·620	*d*♯ 2460·732	*e* 2607·052	*f* 2762·076	*f*♯ 2926·320	*g* 3100·328	*g*♯ 3284·684	*a* 3480·000	*a*♯ 3686·932	*b* 3906·168
Five ,, ,,	*c* 4138·440	*c*♯ 4384·528	*d* 4645·240	*d*♯ 4921·464	*e* 5214·104	*f* 5524·152	*f*♯ 5852·640	*g* 6200·656	*g*♯ 6569·368	*a* 6960·000	*a*♯ 7373·864	*b* 7812·336

Chapter V.

Combination tones.

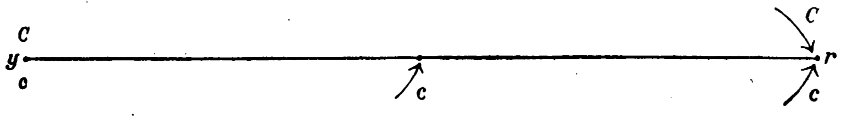
According to Tyndall, combination tones are said to have been first noticed by the German organist Sorge in 1745. Without knowledge of this, the violinist Tartini noticed them in 1754, and they were made known as Tartini tones. Combination tones may be heard when, let us take for example, the small octave *c* and *g* (prime and its fifth) are loudly played together on an organ; the lower octave of the prime *c* can then be distinctly heard. This combination tone, however, does not come from any of the pipes, nor is it a partial tone of them. It is the result of the difference between the intervals of the two tones, and is for this reason called a "difference tone". If we assume that the prime has 100 beats, then its fifth will have 150 within the same period of time; the lower octave of the prime would have 50 beats. The difference between the prime with 100 and the fifth with 150 beats is 50 beats; so we receive the lower octave of the prime as difference tone. Helmholtz insists that, if a combination tone can be produced by the difference between the vibrations of two unequal tones, the sum of such vibrations ought also to produce a combination tone or summation tone. In this case we must adopt the theory that the ear is an adding and subtracting apparatus. Of course, Helmholtz, with his belief in the ear scale, will not—nay, cannot—admit this. Although Helmholtz declares that he has heard summation tones, to our knowledge no one else has;

therefore there is no reason why we should believe in them. We will endeavour to disclose the true cause of the origin or existence of these combination tones.

If two clocks having long pendulums are hanging on the wall of a room, and both ticking slowly and loudly, we notice how the difference in the ticks and the motions of the two pendulums causes the formation of peculiar intervals, which convey to the ear the impression of peculiar figures. Thus listening, we become aware that the ticks occur at times further apart, at times nearer together, and then synchronously. I designate the figures formed by the intervals of the two pendulums, and which produce by no means an unpleasant effect,—a concord. If we remove one of the long pendulum clocks, substituting in its stead a so-called mantel clock having a quick tick, there no longer will be any regular figures formed by the intervals of their combined tickings; but we hear a disagreeable jumble or confusion, which produces a most irritating, unpleasant effect, and may well be termed a discord.

Bearing in mind the above illustration, we find that in like manner when two or more tones whose beats are not synchronous are sounded simultaneously, intervals are formed which do not exist when the same tones are struck singly; consequently it is these smuggled, creeping-in-between intervals which give rise to the combination tones. Tones which are in unison produce no combination tones because their intervals synchronise, thus forming one interval,—i.e., in the case of the three strings forming any note on the piano. Prime and octave are in unison, therefore they give no combination tones.

Fig. 2.

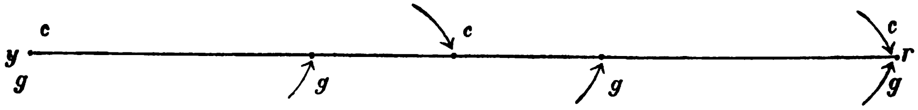


The line y—r represents the measure of the tone interval C; C is the prime and *c* the octave; y is the starting point of these two tones. When the tone C commences its second beat the first has already made the distance from y to r, so that the interval of the tone C is equal to y-r. The octave has double the number of beats, so that when these two tones are sounded together the interval of the prime is divided in the middle by an intervening beat of the octave. Standing on the bank of a pond with smooth, unruffled surface, having in our hands two white and three black pebbles, the white stones to represent the beats of a prime, and the black stones those of its octave, at the word *One,* we throw one white and one black stone simultaneously into the water, likewise of course into the same spot. We perceive, as both stones reach the water together and at the same instant, that the double throw produced only one beat, causing a small ring to appear on the surface of the water, which continues to spread from its point of origin. At the word *And,* a black stone representing the beat of the octave is thrown into the water; and at *Two,* the last two stones, black and white respectively, representing the beats of the prime and octave, are thrown in together. We have now three rings upon the water, equidistant one from the other: the interval of the prime is destroyed by the intrusion of the interval of the octave.

If the pendulums of two clocks were so synchronous in their movements that the ticks of one coincided with every second tick of the other, we should be under the impression that all the ticks came from one pendulum, because we would have to deal with one interval only. Owing to the fact that the intervals of the octave and prime are synchronous, we have that unison of which we have already spoken, and unison cannot give rise to combination tones. As the double tick of the two pendulums does not cause the loss of the divided interval, neither does the simultaneous sounding of a prime and its octave destroy the interval of the prime; because, when the double beats of the two notes coincide, the interval of the prime is especially marked. So long as we can distinguish one beat from others, so long can we also distinguish the intervals between these beats. Nature has done much to assist us to discriminate between the beats of one tone and those of another. For instance, the beats of the prime are more massive than those of higher tones; and, although this is not very noticeable from tone to tone, it is very much so by the time the eighth tone or octave is reached. This statement will be proven by the proportions of the dimensions of the tools which in tone production give the first important beat. We find that those organ pipes which produce low tones are wider and have larger *labia* or mouths than those giving the higher tones. This is not arbitrary, but according to law. Should we attempt to give the long pipes for the deep tones as small a compass as we give to those producing the higher tones, we would receive a partial tone instead of the tonic. The player of a wind instrument compresses his lips more closely to produce high notes than he does for the lower notes. For the deep tones of a piano, thick strings and hammers having wider heads are used, for the reason that the low notes claim a larger extension for their beats than the high notes. Invert this order and the mistake will make itself noticeable. Breadth of tone must not be confounded with power of tone. The shrill sound of a steam whistle has much more power than the tone of a trombone, notwithstanding the fact that the beats of a trombone tone have much greater dimensions than those of a steam whistle. This is to be kept in mind in our explanation of combination tones.

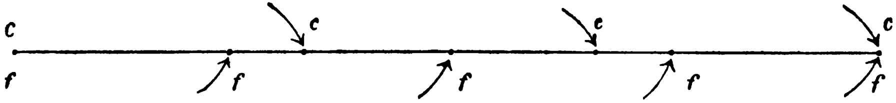
A prime and its octave simultaneously sounded produce no combination tones, but a prime and its fifth do. The number of beats in a fifth are to those of a prime as 3 : 2. The fifth has three beats to two of the prime.

Fig. 3.



In Fig. 3, *c* is the prime and *g* its fifth. As in the foregoing illustration (Fig. 2), we observed that the octave divided the interval of the prime, so does the prime now divide the fifth. If we take a couple of metronomes and arrange their weights in such a manner that the pendulum of one makes three movements to the other's two, and so that the second beat of one falls with the third beat of the other, we shall find that between two long intervals there will be two short ones of half the duration. Just such an effect is caused by the simultaneous sounding of the prime and fifth; and the divided interval of the fifth produces a combination tone whose pitch is the higher octave of the fifth. In addition to this high combination tone, we also find a low tone which we have introduced as a difference tone in the beginning of this chapter. Here this tone arises from the double beats of the prime and fifth; and, since the interval between the double beats is twice as long as a prime interval, this tone is the lower octave of the prime. If we sound a prime and fourth together, we obtain one low combination tone and two high ones. The prime and fourth intervals bear the relative proportions of 3 : 4.

Fig. 4.



We see from the spaces between the notes of Fig. 4 three different lengths of the intervals. The largest interval is that of the fourth, the next in length halves the prime; the combination tone formed by this interval is the octave of the prime. The smallest interval is, since it is contained four times in the prime interval, the double octave of the prime. The lowest combination tone which is produced by the double beats of the prime and fourth has an interval four times as large as that of the fourth, and consequently lies two octaves below it. This result coincides with Tartini tones. For instance, supposing the prime to have 300 beats, then the fourth will have 400, the difference being 100 beats; we may call this tone a difference tone. Nowhere, however, do we find a summation tone.

Hence we see that the more the numerical proportions of two or more tones increase, the more combination tones are formed, the more unequal become the intervals among themselves, and the time measure of the beats becomes more irregular and rugged; the more irregular the beats' time measure, the more the rhythm and play of the intervals is lost, and concord gives place to discord. As combination tones take their existence from the play or variations of the intervals, they are difficult to detect in concerted music. With the aid of three metronomes, we can easily render the rhythm of any chord visible. Take the major chord C E G, the proportions being 4 : 5 : 6. Arrange the three metronomes so that the fourth beat of one, the fifth beat of the second, and the sixth beat of the third occur together. Now take the chord C E B, whose proportions are 8 : 10 : 15; adjust the weights of the metronomes to suit these proportions, and we shall make apparent from the play of the intervals of the two chords respectively what is concord and what is discord. Judging from this, every one will perceive that concord or discord produced by notes simultaneously sounded must arise from the figures formed by their intervals which originate in the rhythm of the measure of their beats. In order that everyone may obtain an illustration of what is meant by "play of the intervals," I advise a visit to a stone yard where from thirty to forty men are employed with pick hammers. Although the beats on the stones do not fall at the same time, there is still a certain rhythm in the entire work without which the ears of the men would not permit them to work together. This rhythm is very like a beautiful symphony.

I was once asked: "If two notes in unison were sounded in such rapid succession that the beats of one tone should begin a trifle later than those of the other, would a combination tone arise out of the interval thus caused between the beats?" As the same question had occurred to me, I will answer it here. This subject has caused me much thought and study. We must consider that the beats of the standard a^1 have each the duration of only $\frac{1}{435}$ of a second, and that during this space of time the note must be repeated. Accidentally I stumbled upon the solution. One day while engaged at a piano I discovered that the hammer head, instead of being level, was inclined to such an angle to the three strings that when lightly struck in rapid succession the strings sounded consecutively instead of simultaneously. No combination tones arose. Although the strings were tuned in perfect unison, I noticed a slight altering of pitch or a slight discord among the strings, which disappeared however when the hammer head was properly adjusted. Should we start one metronome of two beating exactly the same time a little before the other, we would miss the change and play of the intervals, because the beats would never coincide: thus forming no rhythm, as they would produce one if the beats met and parted. Hence we may assert that, if the same tone is rapidly repeated, no combination tone arises. The same is true of a prime and its octave.

Chapter VI.

Overtones (harmonics) of piano strings.

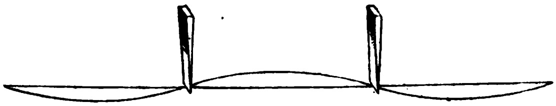
Certain tones of remarkable purity can be obtained from the horn without any artificial or mechanical aid. These tones are called natural tones, because they are produced by a natural division of the column of air in the air chamber. A horn blower can with very little trouble cause the air to divide itself into two, three, or more equal parts, whilst it is more difficult to compel it to vibrate in unequal parts. We learn—for instance, from an organ pipe with small dimensions—that with strong wind compression and without any special aid it gives not the fundamental but some overtone. As with the column of air, so it is with the piano string: it possesses the power to produce tones at every complete or full division, without assistance from us, and forms nodes at one half, one third, one fourth, &c., of its length. Through this we obtain not only the fundamental tone but also natural tones, which we designate as partial tones because they arise from the division of the string; or, as they are added to the fundamental tone, they are also known as side tones; as their pitch lies higher than the fundamental tone, they are termed overtones or harmonics. By experiment we may discover the notes of a string, and without allowing the fundamental tone to be heard we can render the overtones audible.

For the purpose of finding or locating these nodes we make use of wooden wedges. The string will sound when divided into equal parts, but it will remain mute when unequally divided: hence we employ this last mentioned property to enable us to locate the nodes. We will endeavour, with the aid of a wedge, to find the middle of a long, smooth, uncovered, steel string. Measuring the distance with the eye, we apply the wedge to what we consider the middle. If upon striking the string we obtain no sound, we continue to agitate it and slide the wedge up and down upon it, using a certain amount of pressure. When the wedge rests upon the node we hear the octave of the fundamental tone. In this the second tone of the string we have found the first overtone. To assure ourselves that the string is able to form the nodes of itself, we strike *c* on the piano, carefully depressing the key so that the hammer does not touch the string, and then raise the damper. Still continuing to hold down the small *c*, we strike c^1; we find upon removing our finger from c^1 that its tone is distinctly sounded by the strings of small *c*. This is no illusion, for, allowing the damper to fall upon the strings of small *c*, the repeated c^1 ceases to sound. Hence we assert that the strings themselves made the node, for c^1 can only be produced by a string measuring one half the length of small *c* string.

In the foregoing experiment we found the first overtone through dividing the string exactly in halves. If the string be divided into three equal parts we produce the second overtone, which is the fifth above the octave or the twelfth above the fundamental tone. By this division the string forms two nodes, and we will now find one of these as before through the sounding of the string. By placing the wedge at about one third the string's length, we glide until the string sounds the twelfth of the fundamental tone. We have now found the node, and have thereby divided the string into one third and the remaining two thirds. Now, since the one third division gave us the twelfth, the remaining two thirds must give the fifth of the fundamental tone; and strangely we hear the twelfth only,—a certain sign that the string of itself forms another node, dividing the other two thirds. This proves that a string cannot vibrate in unequal divisions. In Fig. 5 we observe that the motion of the strings is waved. We follow the experiment still further, and mark the node by a certain colour so that it may remain visible to the eye. Finding the other node in the above mentioned manner, we now fasten the two nodes by means of two wedges. The string will give the same sound and the same tone as before. By proceeding as mentioned, we may divide the string into any number of equal parts, discovering the overtones.

The tones which can exist in any string are the following: prime or fundamental tone, octave, twelfth, double octave; of the latter, the third, fifth, seventh, ninth, &c. The actual overtones are much less audible than are the experimental ones. Even in the case of the longest strings—which, of course, contain the greatest number of overtones (harmonics)—the unaided ear will be unable to detect many of those above named. It is always difficult to detect the first three overtones of the fundamental: close attention and practice are requisite. Nevertheless, I have found many pianos—not of the highest class, either—on which with the unaided ear I have detected a great many overtones. If I do not err, Helmholtz asserts that by means of an acoustic apparatus he has distinguished the sixteenth overtone of a string.

Vibrating in its entirety, a string forms but one curve; we have seen, however, that under certain conditions two, three, four, or more curves may be formed. We call the junctions of the curves the nodes of rest. Thus, a string divided into three equal parts will have two nodes of rest and two fixed nodes or fixed extremities. It is remarkable that in the experiment illustrated by Fig. 5 we may agitate the string at any place after removing one of the wedges and still obtain the same tone; but, agitate it at the spot or node of rest before occupied by the wedge, and it remains silent. We see that in striking the



(Fig. 5.)

string with the hammer at such a node of rest, the division of the string thus formed will not permit an overtone to be produced. For this reason, Helmholtz thought to benefit the piano makers by recommending them to have the hammer strike at the seventh or ninth division of the string's length, because in so doing the seventh or ninth tone respectively, neither of which harmonises with the entire sound mass of the string, will be ejected. Piano makers did not hesitate to heed this advice, but the more intelligent soon turned from the Helmholtz idea because they found that the tone is benefited by allowing the string to be divided into an equal number of parts. If the string is divided into an uneven number of parts—for instance, by allowing the hammer to strike at one seventh the string's length—then each curve will demand two sevenths of the string's length, and hereby we receive three and a half curvilinear vibrations. However, the waves formed by a vibrating string must be full or closed, because a string cannot vibrate in half waves. Now, as three waves are formed when the hammer strikes at one sixth the string's length, and four waves when the hammer strikes at one eighth the string's length, the string struck at one seventh its length is in an undecided movement, and this state of the string is plainly audible in the tone produced. Helmholtz teaches, according to the wave theory, that the first overtone or the octave is produced by the string undulating with two waves, the second overtone with three waves, the third with four waves, &c. Helmholtz, as a philosopher, should have recognised the impossibility of having a string form all these divisions at the same time without having the one wave disturb another and thereby causing the string to rest. During one period of vibration the string can form only one certain undulating line beside its upward and downward movement. The overtones come from a different source, as we will see hereafter. I protest against Helmholtz's opinion that the overtones blend into the sound mass where they cannot be singled out, their existence being only disclosed in the sensation; and that the character of the fundamental tone is determined through this blending with the overtones. He seems to have ignored the fact that a strong tone can so completely overpower a weak one that the ear cannot perceive its beats. The last mentioned fact must be familiar to all, for music coming from a distance which is distinctly audible may be entirely drowned by music close by, so that we become unconscious of its existence. To give another example: sometimes we hear all the bass notes of distant music. Why do not the waves of the bass notes carry the waves of the higher notes with them to our ear? Since they do not, why should fundamental tone waves carry overtone waves to the ear?

It may be of interest to learn that, if the divisibility of piano strings were not so great, we should not be in a position to construct such excellent instruments as we do at the present day. Herr Fischer of Leipzig, who for many years has occupied himself with the construction of a tuning fork piano* (Adiaphon) has learnt by experience that when a number of differing tuning forks are fastened to a sounding board the latter will not act. In order to obviate this, Herr Fischer allowed each fork to be separately brought in contact with the sounding-board. If in playing never more than eight forks touch the sounding-board simultaneously, the same will not refuse to act as a magnifying instrument. The sounding-board of a pianoforte is not aroused to full activity unless affected by all the strings. This is due to the great divisibility of the piano string. A tuning fork does not produce the regular overtones of the piano string because it cannot be divided in the same manner, and the prongs of a fork are incapable of curvilinear vibrations. If a tuning fork be struck and then placed on a sounding-board where already a number of forks of non-corresponding vibrations have been affixed, we shall perceive that all the forks are sympathetically affected by the vibrations of the sounding-board, and these sympathetic vibrations re-acting upon the sounding-board will cause it to cease to vibrate. Such is not the case with piano strings. If we strike any particular note on the piano, all the strings whether damped or not in which the

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* A piano with six octaves whose tone resembles that of the organ and cannot get out of tune. The inventor was a clockmaker of Vienna named Schuster. (1820.)

fundamental exists as an overtone will divide themselves in a manner corresponding to the pitch of the fundamental tone. All the strings, therefore, help to arouse the activity of the sounding-board, and this is effected with all the more ease because they are spread out over the surface of the board.

We may call those natural tones which possess the property to sound a tone sympathetic to them much like an echo—sympathetic tones. To the natural tones belong also the side tones which we have found as overtones on piano strings and the combination tones. Generally speaking, there are two classes of tones,—namely, natural tones and tones produced by a mechanical process. Any fundamental tone of a string is a mechanical tone because in its production mechanical preparations are used. For instance, the dimensions and tension of the strings are given their respective proportions, and the string is agitated by a mechanical process. If the mechanical preparations are such that several tones may be obtained from one string, as on the violin, then these tones may be termed fundamental tones, because their existence arises from mechanical arrangements. Two or more such tones can never be produced at the same time on the same string, but the string permits a number of natural tones to sound with any of these mechanical or fundamental tones.

The tuning fork shows us that overtones do not come as regularly from all sounding bodies as they do from strings. Strike a tuning fork with a steel bar, but do not place it upon a resonant body: the side tones of the fundamental are heard while the latter is inaudible. As soon as the tuning fork is brought into contact with a resonant body, the fundamental tone becomes plainly audible. Although philosophers have denied that the side tones of a tuning fork harmonise with the fundamental, I have arranged one so that they did. Why should this be less possible in a tuning fork than in a bell? The movements of both these bodies are like those of a pendulum. Nevertheless, the side tones of two bells or of two tuning forks having the same fundamental may be entirely different. This is, of course, impossible in strings. The fact that, when the major third and perfect fifth of all the bells of a chime are used as harmonic side tones to the fundamental, this will create a strongly dissonant effect. These tones are also the principal side tones of a piano string, and therefore a like discord must arise when their fundamental tones are sounded as chords. Therefore, if Tyndall and Helmholtz say that the first two or three overtones are requisite to produce a good musical sound, we see again that overtones are in this respect only unpleasant musical parasites in addition to the fundamental tone.

Every natural tone of a string is, like its fundamental tone, a single tone. A combination of two or more single tones must produce either a concord or a discord. Numerous patents give proof that the piano makers of a century ago were aware of this property of tones, and that they tried to add harmonic tones to the sound-mass of the strings. We can learn the effect of the blending of the partial with fundamental tones by looking at the practical side of such patents.

It is known that in front and in back of the sound producing portion of the string there is a silent part. It has ever been the aim of piano makers to enliven these silent or dead parts with harmonic tones to sound with the fundamental. In Dr. Oscar Paul's book; "Geschichte des Klaviers," we read that in 1822 Collard patented a second bridge which was placed at the back of the original one. This second bridge was glued like the first to the sounding-board, and was separated from it so that the wire between the two bridges formed an aliquot part to the main string, and so produced a tone which harmonised with the fundamental tone. This arrangement, however, required a separate damper for the aliquot parts. The work of the main string had no direct connection with the parts beyond the first bridge because it rested upon the bridge; in order to secure this connection, the following plans were made by others. In the middle of the width of the sounding-board's bridge agraffes are screwed along the bridge to hold or terminate the length of the string for the fundamental tone. These agraffes permit a direct transfer of the vibrations of the main string to the aliquot part. The extremity of the aliquot part is not, as before, laid upon a second bridge; for, as its tone is intended to blend like an overtone with the fundamental tone, every dependent resonance of the harmonic side tone must be avoided, and therefore the extremity is fastened on the iron frame near the hitch pins.* The front portion of the string is also made into an aliquot part of the string, and here the capo d' astro bar facilitates the connection of the vibrations of the main string and those of the aliquot part. If the part behind the main string is arranged to sound the fifth of the octave of the fundamental tone with a length equal to one third the main string, the portion in front of the string may be used to sound the third of the double octave of the fundamental and must then be equal to one fifth the length of the main string. If this order is properly looked to, the blending of the harmonic side tones with the fundamental tone is insured and the work of the three parts of the string is so connected that the damper of the main string suffices for all three parts.

Some of the patents connected with this tone blending idea may be here mentioned. Pierre Erard invented the *barre harmonique* in 1838. In 1872 Steinway & Sons received the U.S. patent No. 126848 for their duplex scale. Siegfried Hansing received in 1886 a U.S. patent No. 341003 for the hammer stroke on the piano strings, in connection with the aliquot parts of the string.

As to the sound character, this only suffers under the effects of the methods; for the effect of the side tones connected with the fundamental tone is of just as little advantage as we have in practice found the overtones connected with the fundamental tone to be. The sharper and more distinctly the side tones are

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* One such arrangement, combined with a special curvature of the strings, I found in a grand of Mathusheck (New York). In order to unburden the sounding-board of the effect of the curvature, which causes a close fitting of the strings on the agraffe, the curve tends upward on the middle string of the three and its aliquot part, while the other two strings and their respective parts ran downwards; at the following agraffe this order was reversed. The plate had, of course, a higher and lower place for the hitch pins. — United States Patent No. 212029 (granted in 1879).

audible in the fundamental tone, the worse is the sound colour, and such tones must be avoided and removed.

Natural philosophers teach us, after Helmholtz's "Sensations of Tone," that it is necessary for good quality of sound character to have the first five overtones which harmonise with the fundamental tone of a string in the sound mass. However, this is an instance where science may learn from practice how the tone parasites—which the natural philosopher calls overtones, and the practical man names wire tones because of their wirey sound—affect the musical ear. The man of science may be taught how the felt hammer head is pricked with needles so that the softness (or, better said, the yielding) of the felt may facilitate a longer resting of the hammer upon the string, whereby the opportunity to produce side tones is lost. Another help towards remedying this evil is the plan which has been known for over a century and which no other has been able to surpass,—namely, to have the strings come in such contact with the wood of the sounding-board bridge upon which it rests that, with the aid of the curvature of the string around the bridge pins, the string may sink one eighth of its diameter into the wood. All attempts made to hinder this pressure of the string into the wood—for instance, by putting hard layers of ivory or metal plates upon it—greatly facilitated the production of overtones, which again as a consequence gave wirey sounds.

The experienced pianoforte maker is well acquainted with these facts; and it is not a lack of knowledge, as men of science seem to think, which keeps us from applying the theory of blending overtones with the fundamental tones for the production of good sound quality. Let us turn to the method by which sympathetic tones are usefully employed in the piano.

We are all acquainted with the method of employing a fourth string in connection with the three composing a piano string; this fourth string is usually thinner than the other three. Although the various practical applications of this method differ, the fourth string in all must not be touched by the hammer, for this string is only to lend its sympathetic tone to the fundamental of the three strings. The effect produced by this fourth string is insignificant, but when supplied with a damper not harmful to the sound character.* Far more effectual is the arrangement by which a row of dampers is lifted from the bass notes. The best arrangement—which is, perhaps, never to be excelled—is the *forte* pedal. A judicious use of this pedal will bring all the sympathetic tones of the strings in a piano to full effect. This *forte* pedal is, however, not to be looked upon as something new, for Sebastian Erard built his first *forte-piano* in 1785.

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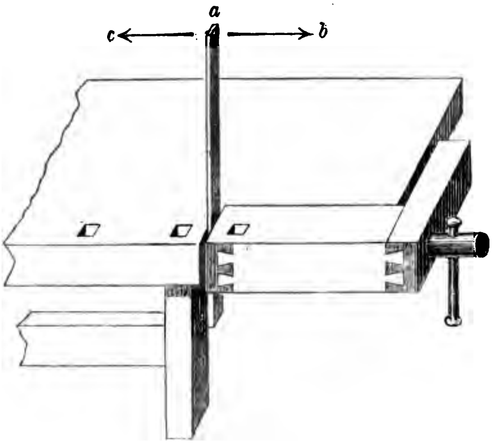
* I mention some of the patents connected with this method. Sohmer of New York received the U.S. patent No. 358946 in 1887 (reverberation). P. Gmehlin of New York in 1885 received the U.S. patent No. 311243 (harmonic scale),—the patented arrangement of the aliquot system of Julius Blüthner of Leipzig.

Chapter VII.

Laws governing the vibrations of the piano string.

A strip of wood having a length of 50 c.m., a thickness of ½ c.m., and a width of 2 c.m., which is fastened in a vice (as seen in Fig. 6), will, when taken by its free end and pulled from (*a*) its position of rest or equilibrium to (*b*), resist this pulling with perceptible force. This force is termed the "spring," and proceeds from the fixed end of the lath. The greater the compelled deviation of the free end of the lath from its equilibrium, the greater will be the power exerted by the spring. If we suddenly release the lath, after having pulled it without injury as far as possible from its position of equilibrium, the spring's power will cause the lath to fly back to this position. Upon reaching (*a*) the spring power is ended; and, if the lath now swings past the point of equilibrium towards (*c*), such movement is due to the force of momentum which the lath acquired during its movement from (*b*) to (*a*).



(Fig. 6.)

A good example of the force of momentum is obtained by shooting an arrow from a bow into the air. We cannot hurl an arrow into space with our hands even nearly so far as it can be propelled by the string of the bow; and yet the force exerted by our hands is much greater than that exerted by the string, which needs be stretched with but little force to throw the arrow further than could the free hand of the strongest man. How do we account for this? The impetus from our hand cannot produce so quick a motion as can the curving of the bow, and upon the rapidity of the motion depends the force of the momentum. The momentum of the lath is concentrated in the extreme point of the free end. Should the lath, impelled by its momentum, pass its line of rest, going to (*c*), the spring is again strained, and its power works against the force of the momentum. The momentum forces the lath from its equilibrium, and the spring strives to bring it back to that position. Therefore, since the spring's power increases as the lath deviates from the equilibrium, there must ensue a cessation of movement while both forces are equally strong, thus paralyzing each other.

This arrest of motion lies outside the centre of equilibrium, and can only be momentary, because the existence of momentum lies in motion and is lost in the stopping of the same; the spring, which has now no opposing power to fight against, hurls the lath back to the equilibrium, whereby the momentum is again aroused and the lath thrown over past the point of rest to (*b*). In this way the lath is capable of making transversal vibrations for some time; gradually the power of the two forces becomes so weakened through the mutual counteraction that an absolute stoppage of motion in the equilibrium ensues which can be broken only by outward influences.

The strength of the spring exists or lies in the stiffness inherent in the lath, while the momentum depends upon the lath's flexibility. Therefore, the stiffer the lath the weaker the momentum, and *vice versa*. Some natural philosophers term these transversal vibrations of the lath and of the prongs of a tuning fork "pendular vibrations," because they are similar to the movements of a pendulum. This, to my mind, is a confusing term, for the reason that a pendulum may move with great rapidity yet (as these movements cause no friction of the matter) give forth no sound; whereas, as demonstrated in Chapter I., a tree swaying slowly in such motion does produce sound owing to the friction of its wood molecules. The same phenomena as in the above mentioned lath, and with very little difference, are observed in the transversal vibrations of the piano string.

If we take a piano string between thumb and forefinger, drawing it upward from its position of rest, we feel the spring power which arises from the elasticity or stretching of the string. A straight line is the shortest distance between two points. Hence a straight line between two points is shorter than a curved line between similar points. When the string, which is already tightly stretched in its position of rest, is pulled from this position, it cannot supply from its own natural measurement the additional length required to form a curve. As soon, therefore, as the string is forced from its position of rest and vibrates, its molecules must be extended in the direction of its length. It is owing to this extension or elasticity that the string obtains its spring, by the aid of which it is always brought back to its position of rest when forced from it. The rest of the process was explained in the experiment with the lath. The spring of the string acts from its two fixed extremities, and the momentum will be found, as the string makes curvilinear vibrations, in the centre of gravity of the string which lies in its middle. The string by its extension and contraction acquires a longitudinal vibration.

So far as I have considered the matter, it is my conviction that any body which produces sound must vibrate longitudinally, by which means the beats can be further propagated. As before stated, no body can produce sound unless its matter be in a state of activity. A positive proof for this assertion is to be found in the action of the stem of a tuning fork. How otherwise than by means of longitudinal vibrations could the activity in the prongs of the tuning fork be communicated through and by its handle to a board?

A piano string, when pulled by its centre from the position of rest, is divided into two definite half lengths, each one forming a half wave. The same is the case when the momentum forces the string from its position of equilibrium, and therefore each wave of the string swings with two joined half waves. A body—for instance, the tuning fork—may also vibrate with two separated half waves. Where the two half waves meet, the momentum makes an invisible node, which is of course situated in the middle of the vibration wave. This node, in contradistinction to the two nodes of rest found one on each end of the curve forming the vibration wave, is termed a node of excitation. Thus each full wave has two nodes of rest and one of excitation. That a division of the wave as above described does exist may be seen when the string is struck by the hammer. The blow excites the molecules of the string, and the consequent longitudinal vibrations of the molecules must proceed from the point at which the hammer strikes the string toward the two nodes of rest of the wave. This separation of the longitudinal vibration—or, better, this procession of the shocks in the string in opposite directions—is equivalent to a division in the wave. When the vibratory shocks or impulses reach the nodes or the full divisions of the strings, overtones are produced, as it is the peculiar properties of strings to give forth tone at these points.

To elucidate: place the handle of a vibrating standard tuning fork on the centre of a piano string (which must exceed in length the string which produces the normal tone), and slide the fork in the direction of the tuning pin block. When a certain point is reached, the vibratory impulses of the fork are assumed by the string, whose remaining length from this point to the bridge pin will produce the tone of the fork. Thus we see that the string can only take up and repeat the vibratory impulses of the fork when a node can be formed corresponding to the pitch of the tone. Allowing the tone of the fork to be a^1 and that of the string *d*, we find a^1 to be the second overtone in the *d* string. Sliding the fork along the *d* string from the striking point of the hammer toward the centre, the tone a^1 will be strongly sounded when two thirds of the string's length have been reached. Likewise, when the beats' molecular vibratory impulses, aroused by the blow of a hammer upon the string, reach the nodes of the string, the respective overtones will be produced.

As the effect of the beats producing the overtones rarely reaches the sounding-board, because the nodes at which the overtones come are distributed so freely on the string, the overtones sound wirey or metallic. This is the case with those overtones which are prominently audible beside their fundamental tone. The beats which a string gives to the sounding-board are those which produce the fundamental tone. For instance, if we strike a tuning fork with a steel bar, the side tones become plainly audible; upon putting the fork in contact with a sounding-board, the side tones recede and the fundamental tone is sounded. The wood of which the sounding-board is constructed has also its nodal lines, as Chladni very ably verifies by means of his sound figures.

Having thoroughly examined the cause and effect of the overtones, we are convinced that, could we eliminate the wirey or metallic tones from a string, the fundamental would gain in purity and beauty, and we should have achieved something productive of pleasing results.

Allowing two boys to hold a cord by the ends in such a manner that the cord is perfectly taut, take hold of it in the middle, drawing it upward from its position of rest, and the boys are pulled toward the middle. In like manner, when the momentum of a string throws it out of its line of rest, the force converges toward the centre, thus preventing the longitudinal vibrations from transmitting any impulse or shocks to the sounding-board. If the cord on its release is to assume its natural line or position of rest, the boys must pull on the respective ends of the same. This demonstrates that, when the spring forces the string back to its position of rest, the molecular friction tends in the direction of the string's ends. The stretching of a string produces no impulses or shocks, which is proven by the fact that the movement of the string after quitting the position of rest becomes slower and slower, thus sympathetically affecting the longitudinal vibrations and their impulses. However, returning to the position of equilibrium, the movements of the string are accelerated, showing that in contracting it exerts the greatest force, at the same time causing the longitudinal vibrations to communicate their impulses (shocks) to the sounding-board. By this means we make apparent to the eye a natural sequence of cause and effect in the production of sound.

In transversal vibrations, the string stretches as it rises, and contracts as it assumes its equilibrium position, acting in like manner as it depresses or goes downward and returns to its line of rest, thus causing a twofold longitudinal vibration during each double vibration. Each longitudinal vibration exerts one impulse on the sounding-board, and each transversal vibration two impulses. The pitch of tones may be determined by an instrument called a syren, which gives 435 longitudinal vibrations to the standard A. Longitudinal vibrations as we have found them were not known to exist in a sounding piano string, so the number of longitudinal vibrations was transferred as the number of transversal vibrations to the piano string. We have found that two longitudinal vibrations come to one transversal vibration; so, in transferring the number of longitudinal vibrations to transversal vibrations, the latter must have been given twice the actual amount. This fact is well worthy of consideration.

It is a peculiarity of the vibrating piano string that it expresses its best tone during its undulating movement. Carefully observing a long string, we find that it vibrates with a single wave or in curvilinear form; however, this curvilinear vibration does not deviate as far from the line of rest as do the wavy movements. As before stated and demonstrated, the number of waves is determined by the striking point of the hammer. Still, there is no law which regulates the number of waves requisite to a given pitch, and one could allow the hammer to strike the string in the middle, as the centre of gravity lies at that point, and it is therefore of the highest advantage to the momentum. A trial will soon convince that the string so struck is not sufficiently firm to resist the blow of the hammer, which is repeated by the sounding-board in the form of a knocking or thumping. To obviate this disturbance, it is necessary to so adjust the hammer that the blow falls upon the part of the string nearer to the tuning pin block, that being the strongest and least yielding part of the piano.

Chapter VIII.

Dimensions of strings.

More transgressions have been made with the dimensions of piano strings than with any other part of the piano. This is because until now there existed no correct directions as to the exact proportions of the dimensions of piano strings. The majority of piano makers copied from pianos which had won a reputation, and not rarely did these copies differ from the originals, made so either involuntarily or by desire. I have recognised, from the numerous queer scales which have fallen under my observation, that there are still many piano makers who are led by the belief that the power and fulness of a tone depends upon the transversal vibration, and that therefore a long string will produce a more singing tone than a short string. As well as can the dimensions for the receivers of the air columns of an organ's pipe work be measured according to fixed rules, so can the dimensions of a piano string, required to best produce a certain tone, be accurately calculated according to a given law. Although the comparison between an air column and a piano string is not altogether correct—as the string is a tone producing and the air column a resonant body—we may still learn from the air column that a body, in order to sound well, must be proportioned in length and width accordingly. It is of common occurrence to find a piano with the thickness of the strings altered in order to compensate for an inferior sounding-board. In planning a piano nothing is of more evident importance than that the length of the strings be proportioned to the work assigned them; the thickness must be similarly proportioned. The transversal vibration is the regulator for the work of the strings and is determined by the flexibility of the same. The more flexible a string, the more its activity changes to inertness; the more the flexibility tends towards stiffness, the more active becomes the string, for the number of its vibrations increases. In shortening a string one half its length, its stiffness increases in quadratic proportion to what it has been shortened, and in the same proportion as its stiffness increases by this shortening its flexibility decreases; the number of vibrations, however, is only doubled. Thus the number of vibrations increases in the same proportion as the string is shortened, and the stiffness increases in quadratic proportion to the increase of the number of vibrations.

Should we desire to double the number of vibrations of a string by means of tension, we must subject it to four times the strain; if the number of vibrations is to be doubled by weight, we must use four times the weight. Hence we see that a string subjected to four-fold weight receives four-fold stiffness, so that the power exercised in stretching a string is in direct proportion to its stiffness. If we determine the mass of the string in the proportion of thickness by the weight, then the weight is to the diameter of the string as 4:1. Thus, if we have four strings of the same length and thickness, with a fifth of the same length but weighing as much as the four together, we shall find upon subjecting all to the same stretching force that each of the four strings will vibrate with twice the number of vibrations as the fifth string (which is four times as heavy as any one of the others). The diameter of this fifth string will be as 2:1 to the diameter of any one of the four strings. This is best illustrated by the following:—For instance, if we have four strings, of which the crosscut has the same area, and if we stretch each string with a stretching force equal to 150 lbs., all strings will have the same pitch. Combining two strings so that they are as one, the cross cut is doubled, and if hereby the stretchingforce is 2×150 lbs., = 300 lbs., the pitch will remain the same. Combining three strings so that they form one string, the area of the crosscut is also increased threefold and the pitch remains the same providing we also treble the 150 lbs., stretching force. With four strings combined the area of the cross cut is increased fourfold or better said, the diameter is now twice as large as that of the single string. The stretching force hereby must be 4×150 = 600 lbs. The number of vibrations decreases in direct proportion to the increase of the string's diameter; but they stand in quadratic proportion when we reckon with the weight mass of the string in its thickness instead of with the diameter. It is understood that the strings here compared must be composed of one and the same material, not one of brass and another of steel.

The weight of the string diminishes its number of vibrations thus: As the double length of a string has also the double weight of the single length, hereby diminishing the number of vibrations by one half, the proportion of the weight of a string in its length is the same as that of the decrease in the number of vibrations; on the contrary, if we calculate the weight mass of a string in its thickness, the proportion is quadratic, because not two but four fold weight will then diminish the number of vibrations by one half. The proportion of the weight in a string length is directly inverse to the number of vibrations; the weight mass of a string in its thickness stands in direct inverse quadratic proportion to the number of vibrations. Here we have seemingly two laws which directly contradict each other: first we find that more weight through additional length makes the string more flexible and thereby dimishes the number of vibrations; secondly we find that more weight through greater thickness stiffens the string but also decreases the number of vibrations. This contradiction may be explained as follows. The first thing to be remembered is that the increase in weight of a string either by additional length or greater thickness affects the *spring* paralyzingly, because the spring has, so to say, to bear the weight. A board lying horizontally, fastened by its one end leaving the other free in air, will, if it is flexible enough, make a certain number of vibrations upon being agitated. Let a heavy body, suitable for the purpose, be placed upon the board and the number of vibrations will diminish the further this body is pushed towards the free extremity. This is because the spring which comes from the fastened extremity of the board has to bear this additional weight, so that by the number of vibrations the power of the weight must be considered with the spring. The additional weight is a support to the momentum, the more so as the weight is pushed to the free extremity of the board where the momentum is concentrated, and therefore the amplitude of the vibrations grows with the greater weight. For we know that the momentum retains a direction it has adopted and that a direct opposition to this direction will dissolve the momentum; the stiffness of a body tends to aid the spring. If we place a weight on the middle of a string, or in other words upon its point of gravity, we slacken the string's movements; double the weight and the movements will be twice as slow. With a thicker string we have not alone the additional weight with which to calculate for the number of vibrations; but, since this additional weight has been given to the string not by adding to it in length but by making it thicker, we have also to count with the stiffness caused hereby. Through stiffness the spring of a string is so increased that, to diminish the number of vibrations by one half, the string must be given the four-fold weight mass in thickness. The consequence is that, by keeping the same length but continually widening the circumference of the string, the number of vibrations will no longer decrease; for the growth of the spring will cause an increase in the number of vibrations, as may be seen by the gradual growth of a steel string into a steel rod. Therefore the flexibility of a string diminishes the number of vibrations and the stiffness increases it.

Though this explanation may seem to be of importance only for the mechanical movement of the string, that is, for the transversal vibrations, the influence which arises from the mechanical movement extends itself even to the tone character. The power of tension, which directly influences the material, transfers every peculiarity in the movement of the transversal to the longitudinal vibration; so that, when the length or thickness of a string is meddled with, the incorrectness will be noticeable in the quality of the tone character.

A regulation for the length of strings is given us through the fact that the stiffness of a string shall increase and diminish in the same, but not in quadratic, proportion to the increase and decrease in the number of vibrations. Practice teaches us that, if we lengthen or shorten the strings according to the natural tonal proportions—for example, if we double the length of a string to obtain the lower octave, thereby increasing the string's flexibility four-fold—we receive an inferior tone quality. We must shorten the string of the lower octave by one quarter in order to lessen its flexibility so that its stiffness may have decreased in the same proportion as the vibrations have decreased. But by shortening the string we augmented the number of vibrations to such an extent that we raised the pitch of the tone. To lower this tone we must reduce the tension; this, however, decreases in quadratic proportion, so the flexibility of the string is again increased to such an extent that, notwithstanding the shortening of the string, we are again at the starting point. We learn from these facts that the rise in pitch due to the shortening of the string is only to be counteracted or remedied by an increase in the thickness of the string. In comparing the proportions of length and thickness by means of weight calculations—since weight is to give us our decision—we find that, as proportion of length to that of thickness is quadratic, we must shorten the string for only one sixteenth of its length, leaving all else to the string's thickness.

In reckoning and determining the length of the strings, I select as a starting point the three strings of the highest tone on the piano. I make this selection because this tone requires the most exact calculation, for the minutest difference in the length of its string will produce a difference in pitch. The most practical length for c^5 is 5·2 c.m. However, we must discriminate between the natural and the actual length of a string. To explain: If c^5 has 5·2 c.m. string's length, the natural length of c^4 would be 10·4 c.m.; its actual length is one sixteenth less. As it is with c^5 and c^4, so is the difference with all tones from octave to octave. The actual length of c^4 being found, a thicker string is used; the thickness again lowers the pitch as much as it was raised through shortening the string. We obtain the natural length of c^3 from the actual length of c^4, which being 9·75 c.m. places the natural length of c^3 at 19·50 c.m.

The following table gives the lengths for the octaves in uncovered strings:—

	Natural length of strings.	Differential length.	Actual length.
c^5			5·2 c.m.
c^4	(5·2 × 2) = 10·4 c.m.	minus (10·4 : 16) = 0·65 c.m.	= 9·75 c.m.
c^3	(9·75 × 2) = 19·50 c.m.	minus (19·50 : 16) = 1.219 c.m.	= 18·281 c.m.
c^2	(18·281 × 2) = 36·562 c.m.	minus (36·562 : 16) = 2·285 c.m.	= 34.277 c.m.
c^1	(34·277 × 2) = 68.554 c.m.	minus (68·554 : 16) = 4·285 c.m.	= 64·269 c.m.
c	(64·269 × 2) = 128·538 c.m.	minus (128·538 : 16 = 8.034 c.m.	= 129·504c.m.
C	(120·504 × 2) = 241·008 c.m.	minus (241·008 : 16) = 15·063 c.m.	= 225·945c.m.

On page 142 in Dr. Oscar Paul's "Geschichte des Claviers" we find the following announcement made by the firm Watchl & Bleyers of Vienna, bearing date 1811: "According to mechanical tradition, in order to produce a supposed improvement in the dimensions of strings, it was chiefly necessary to file and to polish. This proceeding so mutilated the measurements that no original octave proportion could be discoved. It is plain that through such crippled dimensions and a stringing the numbers of which had no proportions the conformity of sound suffered. Some may suggest that the conformity of sound may be obtained by a clever leathering. True; but how long will such compulsory conformity last? By a thorough and careful experiment, for which two particular apparatus and a piano with only one string for each tone were expressly manufactured, the length, thickness and most advantageous tension of the strings for the tones of f^3 and the small f were determined. The geometric succession and proportion of the 47 to-be-inserted tones were constructed from these two tones, thus resulting in our octave proportion = 1 : 1·9458608."

I doubt that Messrs. Wachtl & Bleyer achieved an improvement through such a string proportion. The octave proportion which they used made the measurements of the strings decidedly too long. Starting at c^5, by using the proportional number 1·945 the result is as follows: c^5 = 5·2 c.m., c^4 = 10·114 c.m., c^3 = 19.672 c.m., c^2 = 38.262 c.m., c^1 = 74·420 c.m., c = 144·747 c.m.

Measurements of Pianostrings.

The proportion of string lengths from half tone to half tone is 1·0538.

The measurements are given in centimeter.

c 119·92	$c\sharp$ 113·81	d 108 00	$d\sharp$ 102·48	e 97·25	f 92·28	$f\sharp$ 87·57	g 83·10	$g\sharp$ 78·86	a 74·84	$a\sharp$ 71·02	b 67·39
c^1 63·95	$c\sharp^1$ 60·69	d^1 57·59	$d\sharp^1$ 54·65	e^1 51·86	f^1 49·20	$f\sharp^1$ 46·69	g^1 44·31	$g\sharp^1$ 42·05	a^1 39·90	$a\sharp$ 37·86	b^1 35·92
c^2 34·09	$c\sharp^2$ 32·35	d^2 30·71	$d\sharp^2$ 29·14	e^2 27·65	f^2 26·24	$f\sharp^2$ 24·90	g^2 23·63	$g\sharp^2$ 22·42	a^2 21·28	$a\sharp^2$ 20·20	b^2 19·16
c^3 18·18	$c\sharp^3$ 17·26	d^3 16·38	$d\sharp^3$ 15·54	e^3 14·75	f^3 14·03	$f\sharp^3$ 13·32	g^3 12·64	$g\sharp^3$ 12·01	a^3 11·40	$a\sharp^3$ 10·82	b^3 10·26
c^4 9·74	$c\sharp^4$ 9·24	d^4 8·77	$d\sharp^4$ 8·33	e^4 7·90	f^4 7·50	$f\sharp^4$ 7·12	g^4 6,76	$g\sharp^4$ 6·41	a^4 6·09	$a\sharp^4$ 5·77	b^4 5·48
c^5 5·20											

The proportion of string lengths from octave to octave is 1·875.

The proportional number for octave distances which I have taken from the average of those of a number of the best manufactures is as follows: Taking 1·875 as standard octave distance, the result is: $c^5 = 5{\cdot}2$ c.m., $c^4 = 9{\cdot}75$ c.m., $c^3 = 18{\cdot}281$ c.m., $c^2 = 34{\cdot}277$ c.m., $c^1 = 64{\cdot}269$ c.m., $c = 120{\cdot}504$ c.m. We will find this result to correspond with the direction by which we must shorten the natural length of strings by one sixteenth. The foregoing table gives us the piano string lengths in centimètres from c^5 to c. In order to draw up the table I give the proportionate number from half tone to half tone 1·0538.

The mètre system is not alone useful for the calculations but also for the measuring itself, and is by far preferable to the present English foot system. For those not acquainted with the mètre system be it noted that all numbers standing before the decimal point are in centimètres; the *first* number after the point in millimètres, and the second number is the tenth fraction of a millimètre. The mètre staff is divided into one hundred centimètres and each centimètre into ten millimètres. As the fractions of millimètres are not found on the mètre staff, all numbers in the table under 0·05 may be disregarded, and those above may be raised to a full millimètre. For transferring into feet and inches we give the following:—

Millimètre	equals	0·03937	inches	0·003281	feet
Centimètre	equals	0·39371	inches	0·032809	feet
Mètre	equals	39·37079	inches	3·280899	feet

Hereby 25·~~3~~4 millimètres make an inch.

Mark the string lengths according to the table on a wooden strip, beginning at 5·2 centimètres length. Hereby the differential proportion of the string lengths in their geometric succession may be discerned with exactness, and every mistake which the eye perceives in the geometrical succession may be corrected and altered on the strip. Use great exactitude in the measurements of the strings for high treble tones. If, for instance, the string for the tone c^5 were given a length of 5·5 c.m. instead of 5·2 c.m., as in the table, the three additional millimètres would lower c^5 a semitone; for 1·06 is the proportional number of half tone interval and $5{\cdot}2 \text{ c.m.} \times 1{\cdot}06 = 5{\cdot}5$ c.m. But the string is to produce c^5 and not b^4; and therefore the stretching force of the string, if this be 160lb., must be raised to 160 × (1·06 × 1·06) = 180lb.

Be it stated that it is exceedingly advantageous to the tone quality to keep the strings of the first three or four tones of the uncovered strings a little shorter than given in the table, for the reason that the strings on the sounding-board bridge must at this end not lie too far apart. Although every experienced piano builder takes care that one of the sounding board bars or ribs is placed under the sounding board at the end where the sounding board bridge terminates, this strengthening is not competent to make the counter shocks which are given by the sounding-board, especially in violent playing, ineffectual; to gain this the strings must aid one another through their pressure on the bridge. This can be attained only when the strings lie closely together on the end of the bridge, and not as is often the case in upright pianos at great distances from one another.

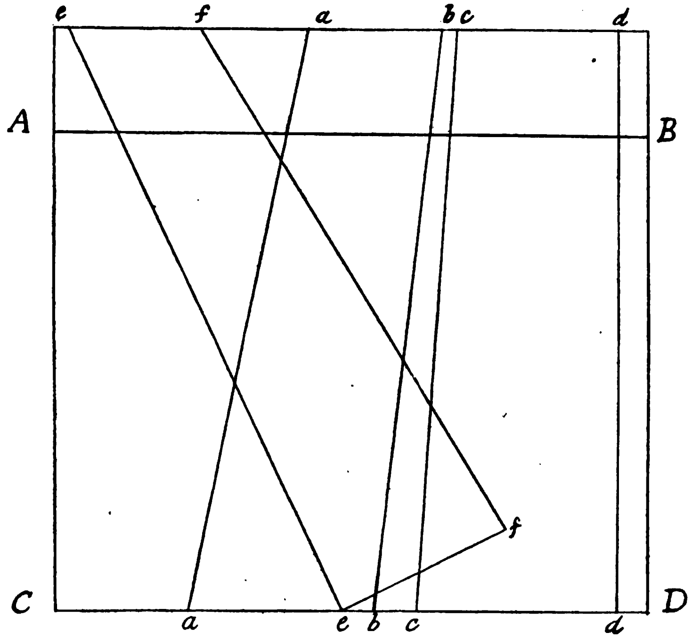


Fig. 8.

A geometrical proportion must exist between the distances separating the strings, for in the symmetry of a scale's construction partially lies the guaranty for the equality of tone. I would like to say that a geometrical proportion for the distances between the strings is best found if the line *d-d* (Fig. 8), which in the drawing of the scale represents the middle string of the three which produce the highest tone on the piano, be drawn at right angles to the line *c-d.* The line *a-a,* which represents the middle of the first three uncovered strings, must be definitely placed. The line *A-B,* which indicates the striking points of the hammers, is the first which must be drawn in drawing the scale, and on this line the middle strings of the different notes must next be marked with a distance of 1·3 c.m. between them. In this division the iron bars, &c., must be remembered. Just as equal divisions were made on the line *A-B,* equal divisions must be made on the line *C-D* for the strings which are to occupy the spaces *a-b* and *c-d.* As soon as the points marked on the lines *C-D* and *A-B* are connected we will find through the lines thus drawn and supplied with the points for the respective terminations of the strings a clue for placing the bridge pins and for the form of the bridge. In marking the points at which the holes for the tuning pins are to be bored the radius of the pins must be considered; in placing the bridge pins this is not necessary. An even division must also be made on the line *e-f* for the covered strings. The space *b-c* is for the iron bar. The line for the agraffes, or the curved piece, on which the strings rest has been measured from the hammer line *A-B,* before the string lengths were determined and placed upon the respective lines representing the strings. The distance from the hammer line to the agraffes &c., in the highest treble is $\frac{1}{12}$ of the string's length; at c^4 $\frac{1}{10}$; at c^2 $\frac{1}{8}$; use $\frac{1}{8}$ up to the sub-contra A. The bass strings swing easily with four waves on account of their covering (as do those strings which are struck at $\frac{1}{8}$ their length,) this system can be applied up to the one lined octave. Applying this system in the treble part, the stroke of the hammer upon these short strings affects the sounding board so that a knocking sound arises: in order to avert this, we take the striking point of the hammer at a part of the string which offers it more firmness and does not unpleasantly influence the tone character. The number of waves with which a string swings does not influence the pitch of a tone; but, as we have learnt before, it does affect the overtones. When a string is struck at one eighth its length, the octave tones of the fundamental tone are favoured; when the string is struck at one tenth its length, the third of the double octave profits. After having thus settled with the string lengths of the uncovered strings there remain only the proportions of thickness and the tension of the strings to investigate.

The succession of the numbers of the strings, as they are supplied to the factories for stringing the instruments, is so arranged that the increase of the strings' diameters according to their numbers shall form a geometric proportion. In comparing the diameters of the strings from different factories it is probable that No. 13½ of one is equal to No. 14 of another; for this reason be it here said that unless otherwise stated the Poehlmann wire has been used for the experiments described in this chapter. The diameters of the strings were measured with Brown & Sharpe's (Providence, R. I.) millimètre gauge; and as the result of the diameters of the Poehlmann wire strings thus measured is identical with the statements made by Alfred Dolge, which were published on June 14th, 1884, in *The Musical Courier* and in which the diameters of strings of several other manufacturers are mentioned, I bring these statements without guaranteeing their correctness.

Measurements of diameters.

Wire number.	13	14	15	16	17	18	19	20	
Poehlmann	0·770	0·825	0·880	0·920	0·975	1·020	1·075	1·125	Millimètre
Houghton	0·780	0·825	0·875	0·925	0·975				
Smith & Son . . .	0·790	0·865	0·900	0·950	0·955				
Felten & Guillaume	0·800	0·860	0·920	0·940	0·975				
Washburn & Moen .	0·800	0·840	0·860	0·900	0·960				
Roeslau	0·780	0·840	0·880	0·960	0·995				

(Brown & Sharpe's millimètre gauge used.)

According to the goodness of the material used and the size of a string's diameter results the power of resistance with which it opposes the stretching force. A string No. 13 broke on the testing machine at a strain of 240lb.; string No. 14 broke at 261lb.; No. 15 at 290lb.; No. 16 at 315lb.; No. 17 at 350lb.; No. 18 at 385lb.; No. 19 at 415lb.; No. 20 at 435lb. When carefully employing the stretching force, strings will often bear several pounds more; so, for instance, a No. 13 string broke while in a hanging position—not as on the testing machine at 240lb. but at 265lb. We know that the surface of the crosscut of a string with double diameter has been widened four times. Therefore a string with double diameter must contain as much in the surface of its crosscut as four strings of single diameter; self-evidently, four strings taken together can bear four times as much as any one string, provided the diameters of all four strings are equally large. If we desire to compare the bearing power, say, of string No. 13 with that of string No. 19 we first find the area of the No. 13 string; if we divide the diameter of the string 0·77 m.m. by two, square the result and then multiply by $\frac{22}{7}$, the area of the crosscut of string No. 13 is 0·46585 m.m. and that of No. 19 string with a diameter of 1 075 m.m. will equal 0·90766 m.m. The diameters are to each other as numbers 1:1·95; for this reason the string No. 19 should bear 1·95 times the stretching force of string No. 13. As string No. 13 broke on the testing machine at 240lb., string No. 19 should bear (240 × 1·95 =) 498lb. The practical result on the testing machine, however, proved that the string No. 19 broke at 415lb.; and therefore the thin string can bear more in proportion than the thicker string. The same result has been given by various experiments, and the phenomenon may arise from the peculiar way in which the thin strings are wrought.

The absolute solidity of a string depends upon the property of the power of attraction with which the molecules of a string resist a separation by means of tension. Absolute solidity and tractability are of special importance in piano strings; though the last named property may be as perfect in strings made of different material, yet there are none which excel the steel string with its absolute solidity. Thus we have learnt that the absolute solidity of a steel string of 1 m.m. diameter can with great certainty bear a stretching force equal to 380lb.; so a string of 2 m.m. must be able to bear four times as much—that is, it must bear 1500lb. According to this, a platinum string of 0·886561 lines (a line is equal to 2·256 m.m.), that is of 2 m.m., is said to bear only 255lb.* The absolute solidity in a steel wire is, according to this, six times greater than in a platinum wire. Iron wire, the absolute solidity of which stands to that of platinum wire as 540 : 255, is therefore 2·12 times greater than the latter, but 2·83 times below steel wire in absolute solidity. Aluminium wire is said to be far behind iron wire in its absolute solidity, and therefore neither this nor any of the wires before mentioned can be so well suited for stringing pianos as is steel wire.

We have, however, not alone the absolute solidity of different materials to consider, but also that of strings made of the same material; the strings of one manufacturer may excel those of another in absolute solidity. Two strings may possess an equal degree of absolute solidity, but the one may be more docile than the other; the one possessing the greater docility is preferable to the other for stringing. If old instruction books contain the assertion that the string produces the best tone when it is at the point of breaking, this is by no means true of the present steel wire with its absolute solidity. In the table for string lengths to their pitch (page 76) we find measurements which have proven to be the best, although many changes in the length proportions have been attempted by some of the best manufacturers. In establishing the length of a string in relation to its pitch, the establishment of its molecular tension has also been formed; it is not in our power to change by means of thickness or thinness that proportion of a string's resistance which it exerts against its tendency to break. If, for example, we choose a string with double diameter for c^5 (the highest tone on the piano), we know, first, that we must stretch this string with fourfold stretching force; secondly, that this string can bear four times as much as a string of single diameter, so that the proportion of the power

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* Dr. Oscar Paul's "Geschichte des Claviers", page 121.

of resistance cannot be changed in a string of double diameter. To elucidate, we may take for the tone c^5, which according to the table receives 5·2 c.m. string's length, a string No. 20 in lieu of the string No. 13½. The stretching force of this string would be, in proportion to its diameter, 320lb.;* and, although the string can well bear more than this weight (it broke on the testing machine with 435lb.), we cannot take the proportion of a string's thickness discretionally.

Every piano maker will know that the string No. 20 with a length of 5·2 c.m. for the tone c^5 is not properly proportioned either in length or thickness to carry out satisfactorily the exterior and molecular movements of the string. For this reason it has been found after many trials that for c^5 the string No. 13½ with a diameter of 0·795 m.m. and a length of 5·2 c.m., whereby a tension of 160lbs is used, gives the best result.

On page 84 is a table for stringing the piano with uncovered strings. From this we see that the presiding endeavour is to subject thick and thin strings to an equal stretching force. It may be seen from the following why the strings are all subjected to nearly the same stretching force, although the thicker strings can bear more than the thin strings; so that, for instance, when the thin string No. 13½ gives its best tone when subjected to a stretching force of 160lb, string No. 20 ought to give, according to its diameter, the best tone at a stretching force of 320lb. We have learnt before that, in calculating with the flexibility of a string, the number of transversal vibrations must be duly considered. A string which, for example, gives 200 transversal vibrations within a second demands for its work a greater amount of flexibility than a string having 2000 of these vibrations within the same space of time. It is evident that the molecular movements which arise with the string's expansion and contraction, or in other words which arise with the string's longitudinal vibrations, must be considered. Just as a rubber band will produce sound

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* If a certain note is strung with thicker wire, then, as the numbers increase, twelve pounds additional force may be calculated for every half number.

How many tones are strung with the same wire.	Names of Notes.	Length of strings in centimètres.	Wire numbers and diameters of strings in millimètres.	Pounds of strain.
3	B C♯	not standard	20 (1·025) ↓↑	
6	D G	104·33 80·29	19 (1·175)	150 160
6	G♯ C♯	76·18 58·63	18½ (1·045)	149 159
6	D^1 G^1	55·64 42·82	18 (1·020)	150 160
6	G♯^{1} C♯^{2}	40·63 31·25	17½ (1·000)	153 164
5	D^2 F♯^{2}	29·66 24·05	17 (0·975)	158 164
4	G^2 A♯^{2}	22·82 19·50	16½ (0·945)	157 163
6	B^2 E^3	18·51 14·25	16 (0·920)	152 162
4	F^3 G♯^{3}	13·52 11·55	15½ (0·900)	157 163
4	A^3 C^4	10·96 9·37	15 (0·880)	155 162
4	C♯^{4} E^4	8.89 7·60	14½ (0·855)	157 164
4	F^4 G♯^{4}	7·21 6·16	14 (0·825)	156 162
4	A^4 C^5	5·85 5·00	13½ (0·795)	154 160

only when so stretched that its matter is affected, so will a string sound only when its molecules stand under the influence of adequate strain or tension. This straining of the molecules must naturally be much greater in a string which, for example, gives tone c^5 (with 4138·440 longitudinal vibrations per second) than in a string which produces the tone *d* (with only 145·163 longitudinal vibrations per second).

So, through the direction of acoustic instructions, we are now competently able to recognise with the mental vision the working of nature in a piano string; and this enrichment of our knowledge will serve us as a foundation in our researches at the practical side of piano construction. The foundation for stringing a piano consists in giving all strings, as far as possible, a like stretching force. Where this can not and must not be, special reasons must exist for deviating from the regularity. Next we will learn, from what practice lays before us, about the difference in molecular tension.

It is known that the diameter of strings in the succession of their numbers do not permit a special number of wire to be used for each separate note on the piano; that is, several notes must be strung with the same number. Using those thicknesses which are obtainable we cannot escape having a difference in the stretching force of strings upward to 10 lb., since we must string several notes with wire of the same number; since the diameters of the strings in their geometrical proportion are not entirely correct, this difference may in some cases equal 15 lb. This incorrectness does not hinder us from making researches as to the proportion of molecular tension of piano strings. Once again we start at the highest tone on the piano, whose string number is 13½, with a diameter of 0·795 m.m.; the string broke on the testing machine at 253 lb. As the string produces the tone c^5 at a stretching force of 160 lb., the string keeps in reserve a certainty in the power of resistance of its molecules against breaking which is equal to 93 lb. If this result is compared with that of the small octave *d* we may ascertain how great the decrease is in molecular tension of those strings producing low tones. The string of the small octave *d*, with wire No. 19 and a diameter of 1·075 m.m., was broken on the testing machine at 415 lb. If this string No. 19 is stretched like No. 13½ with 160 lb., it will reserve 255 lb. for the molecules' power of resistance. From the proportion in which the reserved power of resistance of the molecules of both strings stands, we find the proportion of the molecular tension of the highest tone on the pianos and of the one lying five octaves lower; the proportion here is as 93 : 255.

Here I would like to draw attention to the fact that tension and stretching force differ vastly; for instance: In order to stretch a string, it requires a certain stretching force. How great this stretching force must be depends upon the resisting force of the material. Thus a rubber band may be tensely stretched by a stretching force which is hardly equal to half a pound, and may thus be made capable of sounding; whereas, should we attempt to stretch a string in a pianoforte with the same stretching force, we should not make the least effect upon the string. The same may be noted with a steel string of No. 7 wire and one of No. 27, for the stretching force which stretched the thin string is not great enough to stretch the thick string.

If we desire to know the proportion of the tension of two unequal strings, we must ascertain their resisting power. For instance, a string of No. 13 wire broke at a stretching force equal to 240 lb. and a string of No. 20 wire broke at a stretching force equal to 435 lb. Stretching both strings in a piano with 160 lb. (as is the average stretching force for pianoforte strings), No. 13 wire will have a resisting power equal to 80 lb., whereas for No. 20 wire there remain 275 lb. Therefore we cannot say that both strings are under the same tension when they are subject to the same stretching force.

From the fact that when the string of wire No. 19 is subjected to a stretching force of only 160 lb., 225 lb. are left to the molecular power of resistance, we see that as the diameters of the strings increase a stage is finally reached where 160 lb. stretching force has not the power to sufficiently influence the molecules of the strings. For this reason we prefer so far as correct length is taken for the string, not to go above the wire No. 20, which has a diameter of 1·125 m.m., in choosing wire for the uncovered strings. With the covered strings then, we begin with the steel wire No. 16 or 17 in order to avoid a break in passing from the uncovered to the covered strings. We must so arrange the length of the string and the thickness of the covering wire that the weight of strain which must be given in accordance to these dimensions will form a good connection with the weight of strain given to the strings of the first two notes of the uncovered strings. In accordance with the increase in the diameters of the steel strings the stretching power for the covered strings must be increased so that the tension may sufficiently influence the molecules of the string.

Larger pianos are given fewer covered strings, and according to the size of the piano the strings of the notes A♯, A, G♯, G, &c., must be counted among uncovered strings. Smaller pianos have the strings of the tones B, *c*, *c*♯, &c., among the covered strings. These same rules apply to grand pianos.

It must not be forgotten that only the steel string produces the tone, and that the covering wire serves merely as a regulator for slower movements of the string with adequate tension; this is not to say that special properties of the covering wire may not influence the tone produced by the main string.

The worth of covering wire lies in properties described in the following:--Firstly, it must have little or no spring so that it will cleave to the steel wire, incapable of loosening itself from the same by means of this spring power; for this reason copper, for instance, is preferable to iron. The extent of the property of various materials to dampen the tone more or less comes into consideration in choosing them for covering wire; as iron dampens tone less than does copper, nickel plated iron wire is in prevalent use for covering the steel strings, and only in grand pianos is copper wire used to cover the heaviest bass strings in order to avoid a double covering. In England the attempt was made in the beginning of last century to cover strings with platinum wire. Decker Bros. of New York are said to have used silver wire as a covering for the steel strings in a piano for the Philadelphia Exhibition. Both attempts are worthless; for, though the strings are far more expensive, no

Covered Strings for upright Piano.

(High 142 c.m.)

Number of Strings.	Name of Notes.	Length of strings in centimètres.	Steel Wire.	Covering Wire.	Pounds of Strain.
1	A_2	128·30	24	22–15	215
2	A_2♯	127·90	24	23–16	180
3	B_2	127·40	24	24–16	199
4	C_1	126·90	23	24–17	190
5	C_1♯	126·40	23	25–17	195
6	D_1	125·90	23	27–17	200
7	D_1♯	125·20	22	27–18	190
8	E_1	124·50	22	28–18	210
9	F_1	123·60	21	28–18	218
10	F_1♯	122·60	21	30–18	220
Two Strings for Every Note.					
11–12	G_1	121·50	21	18	175
13–14	G_1♯	120·20	20	18	185
15-16	A_1	118·60	20	19	170
17–18	A_1♯	116·90	20	19	180
19–20	B_1	115·00	19	20	172
21–22	C	113·10	19	20	180
23-24	C♯	111·10	19	21	172
25–26	D	109·00	19	21	180
27–28	D♯	106·80	19	22	172
29-30	E	104·60	19	23	167
31–32	F	102·40	18	24	160
33–34	F♯	100·30	18	25	157
35–36	G	98·20	18	27	155
37–38	G♯	96·10	18	28	152
39–40	A	94·00	18	29	150
41-42	A♯	92·40	18	30	147
Uncovered Strings.					
	B	112·50	20		135
	C	110·50	20		140
	C♯	108·00	20		152

Covered Strings for parlour Grand Piano.

(Length 210 c.m.)

Number of Strings.	Name of Notes.	Length of strings in centimètres.	Steel Wire.	Covering Wire.	Pounds of Strain.
				Copper	
1	A_2	151·00	25	14½	273
2	A_2♯	149·50	25	15	
3	B_2	157·50	24	15½	
4	C_1	145·40	24	15½	
5	C_1♯	143·20	23	16	275
6	D_1	141·00	23	16½	
7	D_1♯	138.68	23	17	
8	E_1	136.20	22	17	254
Two Strings for Every Note.					
				Iron.	
9–10	F_1	133·50	21	18	196
11–12	F_1♯	130·62	21	18	200
13–14	G_1	127·30	21	19	194
15–16	G_1♯	124·08	20	19	180
17–18	A_1	120·93	20	20	170
19–20	A_1♯	117·87	20	20	178
21–22	B_1	114·88	19	21	160
23–24	C	111·97	19	21	176
25–26	C♯	109·18	19	22	156
27–28	D	106·37	18	22	158
29–30	D♯	104‘65	18	23	152
31--32	E	102·00	18	24	156
Uncovered Strings.					
	F	148·00	20		126
	F♯	146·30	20		136
	G	143·90	20		148
	G♯	139·90	19		142
	A	135·00	19		154

benefit is derived therefrom for the tone. Absolute weight comes into consideration with covering wire, but specific weight with the steel string. If we have three strings—for instance, one of copper, one of brass and the other steel—the proportions in length, thickness and stretching force of which are equal, the copper string will be found to produce the lowest, the steel wire the highest tone; thereby the copper wire has the greatest, the steel wire the smallest, specific weight. The number of vibrations given by strings composed of different material stands as the square roots of their specific weight reversed; for instance, if specific weight of a string composed of a metal which we will represent by *a* stands to the specific weight of a string of metal *b* as 1:9, then the string *b* (provided both strings possess equal length, thickness and stretching force) swings thrice as slowly as the string of metal *a*.

Glancing over the following table containing a list of the specific weights of several well known metals we find that the best material for our piano strings has been found in steel wire.

Platinum—Coined ..	21·34	Copper—Hammered ..	9·00
„ Cast	20·35	„ Wire	8.88
„ Wire ...	19·26	Brass—Wire	8.40
Silver—Cast	10·47	Steel—Wire	7·80
„ Hammered ..	10·51	Aluminum	2·56
„ Wire	10·42	„ Wire	2·50

If we desire to ascertain the vibratory proportion of the different metallic strings we must supply them with equal stretching force, and give them the same length and the same sized diameter. First the square roots of the specific weight of the wires to be compared must be extracted.

Platinum Wire = 19·26 = 4·39
Silver Wire = 10·42 = 3·23
Copper Wire = 8·88 = 2·98
Brass Wire = 8·40 = 2·90
Steel Wire = 7·80 = 2·80
Aluminum Wire = 2·5 = 1·58

According to the foregoing, the vibrations of strings of different metals stand to each other as the square roots of their specific weights, reversed so that if the steel string, according to the square root of a platinum string's specific weight, has 4·39 vibrations per second, the platinum string will have, according to the square root of steel string's specific weight, 2·80 vibrations during the same time. Supposing normal *a* to have 439 vibrations instead of 435, the platinum string would well nigh produce the tone *c*♯ in the one-lined octave—that is, the tone of the platinum string lies more than a half tone interval under the subdominant of the tone which the steel string produces in accordance to the above given description. Keeping 280 vibrations for the number given by the platinum wire, we will find from the roots of the specific weights of platinum and silver wires the number of vibrations for the silver wire. The two roots stand to each other as the numbers 439 : 323, and, as the platinum string has 280 vibrations, the silver string has 280 × 439 : 323 = 380·5 vibrations. After this mode of calculating the various strings of wire mentioned here have, in succession, the following number of vibrations.

Platinum String....	280	Brass String	425·9
Silver String.......	380·5	Steel String.......	439
Copper String......	413·5	Aluminum String ..	778

According to this, an aluminum string stands an octave and nearly four half tone intervals higher in tone than a platinum string.

In the year 1892 various pianos were strung for trial with "compound wire" (Fig. 10), and, although the attempt did not have the desired successful result, the originality of the endeavour will cause it ever to remain of interest in the records of piano building; and it therefore well deserves to be mentioned here. Read what the inventor of compound wire (Lawrence A. Subers) says about it in *The American Art Journal*, published April 16th, 1892:—

"The manufacture of wire for pianos is a great industry. There are from 60,000 to 80,000 pianos made every year in this country alone. Each piano contains from six to seven pounds of wire.

"In the ordinary piano the wires are made of solid steel, the bass wires being wound with copper wire to load them so as to get the required tone. Now, instead of taking a single steel wire say for instance, a No. 13, I take three 0·018 wires of equal length, equal in weight to a No. 13 wire, and twist them together. Then I go through the same process down to the No. 28 wire, which is the smallest used, getting the same weight of metal which is necessary for the required tone in each instance with the three strands.

"I put the three strands through a machine and twist them all one way, each strand with equal tensile strength while being twisted. These strands are not twisted tight enough to injure the wire, but still so tight that the strands will not fly out of place; but when cut with nippers the ends will remain together. The process of putting the strands together makes the compound wire easy to bend, while the solid wire cannot easily be bent. This makes it easier to twist the compound wire around the tuning pins and saves half the time and labour of stringing pianos.

"Then I get my pitch quicker. A piano with solid wire, tuned five or six times a year, would with compound wire need tuning not more than twice.

"I claim I will be able to save a great deal in construction of pianos, at least 20 per cent. in the time of regulating, and one half in the time of stringing the scale. I will save a great deal of the expense in tuning in the factories, as my wire can be tuned a great deal more readily and will stay in place better.

"The great advantage of all is in lengthening out the wires on the last octave. If you can lengthen out your last octave one half inch, the result in evening up the bridge and evening up the power is wonderful. While with solid wire of the best quality 1⅞ inches is the greatest distance between the bridges, I go up to 2½ or even 2¾ inches with wire made in this country.

"I get clear, sonorous, silvery tones, while with the other wire the tones are harsh and metallic. I have seen pianos that in time get to sound like an old tin pan. Much of this is due to the hammers becoming hard. A great deal of experimenting has been done to get a

Fig. 10.

hammer that would not become hard; but nobody seems to have tried making changes in the wires. In all my applications for patents I have run up against only two other inventions in piano wires since 1800. One was that of a man who placed four wires together and wrapped them with a covering. This failed, because when it came to fastening the wire around the pins the four wires were not subjected to equal strain. The other was for a chain contrivance with which to lengthen out the wires.

"In making the compound wires there is a different number of twists per inch, according to the difference in the size of the wires; so you see it is a very intricate system. I use three wires instead of two, or four or any other number, because I have found that with four wires there is a hollow centre and one is shorter than the others, while with two wires the result is not satisfactory. My patents, however, cover any number of wires twisted together.

"One great claim is that on account of the lesser strain to which the compound wires are subjected much can be saved in the weight of the cast iron frame, and consequently in the weight of the whole piano, making a great saving in freightage."

The following tests of Subers' compound wire, regarding its relative pitch and tensile strength, should be read and preserved by every practical piano maker:—

"Poehlmann wire No. 13, one inch and seven-eighths in length, to give C (the last note on the scale), gave the pitch at 135 lb. and broke at 263 lb. The compound wire got the same pitch on the same length of string at 91 lb.; it got the same pitch on a length of two and one quarter inches at 112 lb., and broke at a strain of 180 lb. Poehlmann wire No. 14 at the regular length, to give B in the seventh octave, the last note where this size is used, reached the pitch at 168 lb., C♯ at 189 lb., and broke at 265 lb. Compound wire No. 14, same length between bridges, gave B at 140 lb., C♯ at 172 lb., D♯ at 190 lb., and broke at 220 lb., &c."

If Mr. Subers claims that the pianos strung with compound wire will keep in tune better because of the lesser tension required by this wire than by Poehlmann wire under the same circumstances, this assertion has been proven erroneous under exact trial. For what reason should a string breaking at 180 lb. bear a strain of 91 lb. better than does a string which, under like circumstances, must be spanned with 135 lb. and breaks at 263 lb.? We find from Mr. Subers' own assertion that the proportion in the stretching force of the two strings, which is as 91 : 135, is nearly the same as the proportion which exists between the breakage of the two strings 180 : 263. For example, 91 : 135 = 180 : K. "K" is equal to 267, so that the result only differs by about 4 lb. from Subers' statement. Should we choose a Poehlmann wire which breaks at 180 lb., we need span this thinner string with only 91 lb. for the set pitch. It may be that the diameters of the Poehlmann and compound wire were of equal size, but in twisting three strings together spaces must have been caused in the compound wire between the three strands; so that the mass of material in the crosscut of the compound wire string was less than the Poehlmann single wire, otherwise the three strands, if these together have the same area in the string's crosscut as the single string, would also be able to bear the same strong tension as the single string.

At the close of this chapter the experiment may be given proving that the proportion of stretching force on a string is quadratic to the proportion of its length.

A string No. 13, with a diameter of 0·77 m.m., produced the tone c^3; at a length of

Length in inches.	Strain in pounds.
10	58
10½	64
11	70
11½	77
12	84
12½	91
13	99
13½	107
14	115
14½	123
15	131
15½	140
16	149
16½	158
17	167
17½	177
18	188
18½	199
19	210
19½	221
20	232

The string broke at a stretching force of 265 lb.

The string produces the tone c^3 at a length of ten inches and 58 lb. stretching force. Not altering the stretching force but doubling the length to twenty inches, the lower octave c^2 is produced; in order to raise this tone an octave by means of tension we must load with fourfold power—that is with 58 lb. × 4 = 232 lb. We find in the table that this statement is proven by the practical trial. A second attempt which likewise proves its goodness through practical appliances exists in looking upon c^3 as the third to $g\sharp^2$. If c^3 has a string length of ten inches, $g\sharp^2$ will claim a length of $10 \times \frac{5}{4} = 12\frac{1}{2}$ inches. If we desire to bring $g\sharp^2$ to the pitch of c^3, the proportionate number $\frac{5}{4}$ (which arises from the number of vibrations of prime and third) must be quadratically raised and then multiplied by the number of pounds employed to stretch the string, thus: $(\frac{5}{4} \times \frac{5}{4}) = \frac{25}{16} \times 58 = 90\frac{5}{8}$ lb. We have learnt in the foregoing that a string with a length of $12\frac{1}{2}$ inches will produce the tone c^3 when it is subjected to a stretching force of 91 lb. Also in a third example will we find the quadratic proportion of the stretching force to the string's length proven. For instance, taking c^3 as a fifth to f^2. In order to produce the tone f^2 we must change the string of ten inches to $10 \times \frac{3}{2} = 15$ins., because the number of vibrations of both tones stands as 3 : 2. If now we want to change the pitch of the tone of f^2 to that of c^3 by means of tension on the string, we must employ a power of $58 \times (\frac{3}{2} \times \frac{3}{2}) = 130\frac{1}{2}$ lb. The table gives a stretching force of 131 lb. for a 15 inch string to produce c^3.

Chapter IX.

Sounding-board of the pianoforte.

For over a century experiment after experiment has been made with the sounding-board. Though comparatively few manufacturers found the action and dimensions of strings worthy of earnest study, we may say that every manufacturer has had his own experience through various trials in the branch of sounding-board construction. Thousands of experiments, often of the same nature, were made; and yet the number of trials has not found its end. What property does the sounding-board supply in the pianoforte? Is this property so entirely unknown to us that therefore the sounding-board stands in such a mysterious light to the pianoforte?

It should be apparent to all that the sounding-board is to augment the tones produced by the strings. Unfortunately, such is not the case. Hear the opinion of one of the most intelligent pianoforte makers of his day, H. Welker of Gontershausen, in his book, "Der Clavierbau in seiner Theorie, Technik und Geschichte,"—an opinion which is still adopted by the majority of piano makers, and we will see how it is that a part of the piano, so simple in its construction, can be such a puzzle in its acoustic relation and in the way it should be treated. Welker deems the work of the strings to be of secondary importance, and the principal part for the formation of tone is the sounding-board. "Great results often spring from slight causes," so says a proverb which may well be applied in dealing with the delicate beats of the strings as cause of the tone. The preceding and following practical proofs authorise us to hold the tone production—that is, the workings of the strings—just as important and worthy of notice as the majority of pianoforte makers do solely the augmentation of tone,—that is, the work of the sounding-board to be.

Every disturbance of the workings of a string, whatever be the nature, will (provided that the work of the string has not been stopped) be communicated to the sounding-board, and the result is apparent in the tone. Make thousands of experiments to this end so that we may come to the conclusion that no part of the piano is of more importance and requires closer attention than the strings from which the tone production arises. For instance, strike a string with a hard or soft, pointed or round, hammer; employ thicker strings, thus augmenting the tension; choose thinner strings and lower the tension; change the striking distance for the hammer's stroke upon the strings;—all this is perceptible in the tone. This should by no means imply that we slight the sounding-board,—the augmenting instrument for the tones produced by the strings.

Of the workings of the strings in conjunction with the sounding-board, Welker expresses himself as follows: "Therefore we must look upon the sounding-board solely as the sounding-body and not upon the strings, which are incapable of producing motion in the air sufficiently strong to enable the ear to hear clear and defined sounds, and which, through being struck by the hammer, played upon with a bow, plucked, &c., occasion the sounding-board to vibrate, and thereby in connection with the string's tremor to produce the audible tone."

But not Welker alone deems the work of the strings of minor import, for, among others, Dr. Oscar Paul in his "Geschichte des Claviers" (p. 13), writes as follows: "The mass or the molecules of a transversally vibrating string are far too insignificant to ascribe a real tone to it; not the vibrating, only the agitating body—that is, the string—must be looked upon as real tone tool, but the instrument from which the string draws the tone. We call this instrument the sounding-board."

We will find that not only pianoforte makers, but also the learned, have a peculiar idea of the activity of the sounding-board in conjunction with the strings. The sounding-board is not at all a tone producing, but like the stretched membrane of the drum a sound producing, body, and therefore only sound and not tone can be drawn from it. To become better acquainted with the sound producing bodies. we need only to inspect musical instruments, for among these not only tone producing instruments, but also such as are devoid of tone. have been used to render musical service. To the last named instruments belong clappers, castanets, taboret, drum, and others. Thus there are perfect and imperfect musical instruments. The difference between these two classes consists therein that the perfect musical instruments possess tone producers, which property is missing in the other class (the imperfect musical instruments).

Each separate string of the piano is a tone producer, and the property which enables it to produce tone consists therein that it can repeat in a quick, periodic succession the blow dealt upon it, and can keep up this repetition for some time. This property is not among those of the sound producing body. Only a regular recurrence in a succession of beats will produce tone; as soon as the beats come at irregular intervals no tone is produced, and we obtain a noise from the succession of sounds.

There is a class of tone producers which (like the flute stop of an organ pipe, for instance, or the lips of a horn blower, which are kept in vibration only by constant wind pressure) do not act independently, and at the instant in which they are deprived of the agitation will become inactive. If the tone producers of a tone giving body are removed—say, for instance, the strings from the body of a violin—the violin *corpus* is then only a sound producer and possesses only the properties of the drum,—a sound producer. Giving these two sound bodies strings as tone producers, we again obtain a violin; and from the drum we receive a banjo. We see from this that we can produce a perfect tone giving instrument from the drum.

A sound producer will not sound unless it is hit, beaten, or unevenly rubbed; the strings do *not rub* the sounding body, so they must cause it to sound by means of beats, just as a drummer beats his drum. Every beat causes a sound, and the time interval arising from the periodic sounds gives according to its duration a higher or lower tone. The blows which are given by the strings to the sounding-board spread themselves over it with a sort of electro-magnetic power; and it is this power which conveys to us the beats of a sound producing body through the aërial body. The electric wire of the telephone conveys every sound from the point of connection to the ear; so also every beat (here identical to sound) and the form of the beat coming from the sound producer (the sounding-board) are conveyed to the auditory nerve through the aërial body, which is known to be an excellent sound conductor. The form of the beats mostly determines the sound character. In the workshop of the ear the various species of beats as they are conveyed to the same are changed either into tone or sound. It is by no means improbable that the conveyance of the various kinds of beats is carried on by electro-magnetic means; and, through the progress in the domain of electricity, it will appear more and more probable and true. That our nerves are not void of electric and magnetic phenomena is a well known fact.

The many trials with sounding-boards in pianos were not alone made with wood, but included the attempted use of metals and parchment like prepared skins. Welker states that Johann Jacob Goll of Vienna made sounding-boards of copper and iron for grands (somewhere around the year 1823) and with happy results. J. Blüthner and H. Gretchel, who mention this in their "Lehrbuch des Pianobaues," inserted a question mark between the words, "happy (?) result." Messrs. Steinway & Sons of New York state that they made two grand pianos with aluminum sound-boards for experiment, but that these boards were deficient in that quality of tone which their other instruments possess, and that they could by no means replace the spruce sounding-board.* Welker himself tried parchment for sounding-boards, and speaks of satisfactory results. He writes: "Cedar wood used for sounding-boards gives the sound more

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* In reporting the proceedings of the American Association of Science, *The Tribune* says: "The title of Mr. Springer's paper entirely fails to give to the uninitiated any clue to its true inwardness. The 'latent characteristic of aluminum' is its resonance, adapting it for sounding-boards. A number of aluminum violins were exhibited, and the advantages of aluminum over wood were explained. The 'metallic clang,' which is so noticeable

softness than does pine; it also weakens the sound. Steel and copper sounding-boards cause shrill piercing sounds; parchment gave a full strong bass, but the treble was weak and splashy. The last named defect may be ascribed to faulty work in stretching the parchment, which process caused us much trouble in our experiments." Welker further mentions: "But as all these materials, with the exception of larch wood, are far more expensive than is our pine, it would be foolish to use them except for experiment."

To-day's experience teaches, on the contrary, that iron is used wherever it is possible without deteriorating the quality of tone, thus economising the use of wood. The manifest advantages of the metal sounding-board over the wooden one outweigh the calculations in the difference of cost. Metal is not nearly as much affected by climatic changes as is wood, nor will metal break or burst as does the wooden sounding-board. In addition to this, the fact speaks that the matter of the metal may always be made exactly the same, which is impossible in the use of wood. Had the tone quality in using a metal sounding-board been as satisfactory as in employing a wooden sounding-board, the manufacturers of to-day would not hesitate to grasp the advantage thus offered.

In speaking of the advantages and disadvantages obtained by the use of iron in instruments, be it remarked that there was a time when manufacturers followed the principle of using an iron construction for the customary wooden back. Finally they had to recognise that a wooden back and a tuning block made of wood gave them far greater satisfaction as to the tone quality of the instrument than would an iron construction of these parts. The manufacturers who have closely investigated the matter have drawn the limit for this iron construction at

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in other metals, is eliminated. Messrs. Steinway are building a piano with an aluminum sounding-board. Unfortunately, Mr. Springer claims a patent for this use of aluminium, though it is difficult to see how such an application of this metal can be patented. In the ensuing discussion it was stated that a piano maker at Albany had several years ago been urged to make the same experiment.

the positionally necessary iron frame, which has to bear the drawing force of the strings.

Experiments from time to time have proved that wood is better adapted to resonance than is metal. However, not all species of wood can be used for sounding-boards to the advantage of the tone. The wood of trees bearing leaf foliage is not as well adapted for this use as that of trees bearing needle foliage. Some species of leaf foliage bearing trees furnish timber which ranks under some metals in its resonance. To these species belong the soft wooded linden, willow, poplar, &c. Of the needle foliaged trees, the red pine or spruce (*Pinus abies*) furnishes a good, if not even the best, wood for sounding-boards; and this wood, when sawn and split for use, shows a remarkably even grain and equal distribution of the resin in the entire wood mass, to which qualities perhaps may partly be ascribed the great elasticity of the wood. After the red pine follows next in order the white pine (*Pinus strobus*). The wood of this pine is softer and whiter and contains less resin than that of needle bearing trees, of which may here be mentioned the fir tree (*Pinus sylvestries*), which is a very solid wood and is well adapted for use in piano construction because its richness in resin does not allow it to be easily influenced by weather, and the larch tree (*Pinus larix*). Perhaps the superiority of the spruce (red pine) over the white pine (*Pinus strobus*) lies in the fact that the spruce is free from the peculiar "furry" texture of the white pine.

We see from the properties of the pine that its wood is specially well adapted for sounding-boards, being very elastic, having no surplus of resin or other fatty matter, and is therefore of even grain. As for the colour, that certainly cannot affect the tone.

Metals have also good qualities which might render them desirable as sounding-boards. Some metals have one advantage before all species of wood, which is that their molecules are easily agitated to sound. Take, for example, a sheet of steel and shake it,—sound is instantly produced; but in a board the molecules cannot be agitated as easily nor in the same degree. Furthermore, metal possesses the property that it may be wrought into any form and strength. That which metals do not participate of the good qualities of the pine wood are the fibres and the softer texture between. The pine possesses this last named property in a high degree, and it may be that this gives its wood the precedence over metals; for piano makers have learnt to appreciate that property, estimating the usefulness of wood for sounding-boards thereby. The old violin makers deemed this quality of great importance, as may yet be seen from the bellies of their instruments. Examine a good piece of timber ready to be used for sounding-boards, and note how the fibres run straight through the wood, like strong threads. Examine a fibre, and you will ascertain that it possesses uncommon firmness and tenacity. No leaf foliaged tree has these fibres as pronounced as they are in the needle foliaged, especially in the spruce. The soft wood between the fibres has a loose, dilicate, cellular texture; therefore the fibres lie far more unrestrained than in the hard wood of timber from leaf foliaged trees. In the latter the wood mass is often harder than the fibres; in the soft wooded leaf foliaged trees, the fibres barely exist at all.

As we have now properly placed metals and their properties as related to resonance, let us turn our attention once more to a subject before discussed. Were it really the case that the strings have no other duty than to agitate the sounding-board by means of their vibrations and that the real production of tone came from the sounding-board, then the steel sounding-board, in which the property of sound production is found in so great a degree, would be by far preferable to the wooden sounding-board. If, according to Dr. Oscar Paul's opinion, the strings lured or coaxed the tones from the sounding-board, then indeed there exists no material better suited for the purpose than steel, copper, or iron. From the attempts made, we ascertain that steel, iron, copper, and other sound producing metals may be used in the piano, especially for sound production. Wood, however, is specially beneficial for tone augmentation.

It is the property of some metals, of which iron is one, to sound at the least agitation: therefore all iron parts of the piano, the strings excepted, should never be allowed to sound or vibrate with the strings, for this will cause peculiar sounds in connection with the tone, which evil is often ascribed to the influence of the strings. Neither should an attempt be made to employ these iron parts as helps to the resonance; on the contrary, such evils should be carefully avoided. We recognise that the sounding-board is really an augmentative instrument for the tones produced by the strings, and that the spruce furnishes the best material for this instrument.

Despite all the counter arguments which have arisen from time to time—chiefly, as it seems, for advertisement—the sounding-board of spruce has stood all tests for several centuries, and is still holding its superiority. Let us now deal only with the spruce wood sounding-board, remembering that an even grain with fibres not too close together and an evenly fine texture of the grain, are requisite for good, resonant wood. Old matured wood can have these properties, but not the young wood of trees. In the latter the fibres lie close together, because the cellular texture between them is not thoroughly developed; then the wood is heavier and more solid in its mass, for the cells of young wood contain more resin than those of old wood. Quite often young wood of pine is as hard as the hard wood of leaf foliaged trees, and is as heavy too. During growth the resin is consumed to form cellular texture: the fibres gradually come to lie further apart and the wood thereby gains in looseness and lightness. It is therefore necessary, not alone to examine the grain of boards to be used for sounding-boards, especially if for treble parts, but also to ascertain the weight. Several piano makers have expressed the belief that real hard, close grained wood should be used for the treble in order to obtain specially good tone. I would confute this statement by means of the experience which I have obtained in the many years as an independent piano builder; during this time I made careful experiments with a number of sounding-boards. From the trials, successful and unsuccessful, I can assert that a light board—that is, one in which the fibres were fine and at regular distances from one another—gave the best results in every case. With the coarser grained boards, which were however light weighing in wood mass, powerful treble tones were produced. But these tones lacked a refined singing quality; they were massive and plump. The worst tones were always obtained by the use of a hard, heavy wood, well imbrued with resin. Even in a dead state wood still feeds on its supply of resin; therefore, the older the wood, the less resin it contains. The more the wood loosens thereby, the more independent becomes the grain and it can the more freely execute its vibrations.

Through the consumption of resin, the wood gains in sound; as soon, however, as the resin is all gone, the wood becomes rotten and the texture falls together, whereby the sound of the wood is deteriorated. For this reason, as soon as their wood reaches this period, old violins lose considerably in sound. Never can artificial means prepare the wood so well for the sound as it is prepared by age and its self consumption of resin. The wood needs resin for its conservation. By the consumption of resin, the cellular texture is not strained, much less is it destroyed; therefore old violin bellies sound far better than those which have been artificially prepared. That a great deal depends upon where and how the tree has grown is self evident. If a tree grows slowly the annual rings will be solid and the fibres close together. Therefore only such trees should be used for sounding-boards which have grown quickly and strongly; the latter will be straight, very tall and of specially large trunks. Since the number of annual rings determines the age of a tree, one quickly grown and wide of trunk must have the fibres which bound the annual rings far apart. Through the rapid formation of wood, the consumption of resin will also be rapid to supply for so great a wood mass, and therefore the wood will be looser and lighter, the fibres regularly and delicately grown, and therefore very elastic in their mass. But, so that the new wood of the tree may also be usable, the tree should not be felled until it is fully matured, or even till after the time of maturity. The pine is full grown in its eightieth year, retains its vigour for one hundred and fifty years, and reaches an age of four hundred years.

The sounding-board of the pianoforte may be divided into three principal parts: the sounding-*board*, the ribbing, and the sounding-board bridge. In this wise the modern sounding-board is just like the old; the difference consists in the proportions of largeness and thickness of several parts which, in time, have increased their dimensions with other parts of the piano. So, for instance, in using thicker strings, the proportionate thickness of the sounding-board was increased; the consequent additional strain of the strings required also stronger sounding-board ribs. The principal change which distinguishes the old from the modern sounding-board is found in the bridges of the board, which change has been made on account of the situation of the overstrungs. From the manifold trials the proportions of thickness of the sounding-*board* may be deduced as being 10 m.m. on the upper end, and 7 m.m. on the lower. Sounding-boards of German and American pianos have been found to have a thickness in the treble from 6 m.m. to 12 m.m.; some were even as thick as 2 c.m.

The first given proportions in thickness will be found to give the best results in conjunction with the tension of strings given in Chapter VIII. If the proportion of tension is greater throughout all the strings, then the sounding-board must be made thicker accordingly; if the proportion of tension be smaller, the board must be made thinner in accordance. The position of the sounding-board in the direction of the fibres has been tried in every possible way. Only two principles can come into consideration; either the *board* is to help bear the pressure of the strings, or it is to be shielded entirely from pressure. In the first case the long running fibres must be crossed by the board bridge, so that every strip of the board may be cut horizontally by the board bridge; in the other case, however, one must endeavour to let the fibres run in the same direction as the sounding-board bridge, as far as the curvature of the bridge permits.

Arrangements, for instance, like one which Steinway applied years ago under the name "Resonator," by which a pressure worked from the rims or edges of the board toward the centre —that is toward the sounding-board bridge—or like one as I had patented in Germany dated 1880, working in opposite manner to that aboved describe, and after the principles of which the board was stretched much like to a membrane, are objectionable. Such arrangements can only work one sidedly and therefore only hinder the expansion and contraction of the sounding-board, which certainly cannot be advantageous for the molecular vibrations. With this species of arrangement, however, the matter is by no means ended, for many other kinds have been tried and recommended; some of these would lead one to believe anything apart from their being serviceable to the purposes of a sounding-board. There exist truly curious contrivances which, despite their utter failure, are brought to light again from time to time as remarkable new inventions. One, for instance, is to fasten the rims of the sounding-board on springs or other elastic layers. Such contrivances, instead of promoting the movements of the sounding-board must naturally hinder them. As a string for instance, in order to swing in an undulating movement, must always have its two extremities fastened to something stationary, so should the rims of the sounding-board also be firmly fastened to the instrument. As often as it was attempted to leave but one part on one of the rims of the sounding-board unfastened, just so often has this free portion of the rim proven itself a disturbance to the purposes of a sounding-board. It would be erroneous to suppose that the sounding-board has only molecular vibrations; for in this case a 3 c.m. thick board, like a table top for instance, could fulfil the conditions of a sounding-board. Since the sounding-board has also undulatory vibrations to perform, its stiffness and flexibility must be proportioned to the demands of its movements. Should the flexibility of the sounding-board be too great in proportion to the stiffness, then the sounding-board will be too weak to make undulatory vibrations during violent playing and it will vibrate more in its entirety, whereby the tone will sound dull and hollow as from a barrel; if, however, the board is prevented from vibrating undulatingly through a surplus in stiffness, the tone will sound wiry and jingling. If certain portions of the sounding-board are left loose, contra-shocks may be caused, the influence of which may be felt by the sounding-strings; and for this reason, as before stated, it is preferable to have a firm connection of the sounding-board rims with the instrument.

Special attention should be paid to ribbing the sounding-*board*, for the ribs have many a service to render. The old piano makers recognised the value, if not the necessity, of ribbing a sounding-board. The main service of the ribs to the sounding-board is as bearers, and their position should be carefully considered as such. The bearing power of the ribs best serves the purpose if they are made to run under the sounding-board bridge, and if their length is taken as short as the sounding-*board* allows. The best position for the ribs on the sounding-*board* is, if they lie as angularly as possible to the fibres of the grain of the sounding-*board*; for in such arrangement they find special appropriation to serve as bearers to the sounding-board. It is objectionable to give the ribs as bearers special width, and therefore to lessen the proportion of thickness. It will suffice if the ribs are given a breadth and thickness of 2·5 c.m.; the proportion in width for the longest ribs may hereby be increased to 3 c.m.; the thickness, however, remains 2·5 c.m. The ribbing divides the sounding-*board* into fields; and, through a correct relation of these fields to one another, the degree of goodness of the resonance is partially determined. The sounding-board is not alone given a certain stiffness by the ribbing, but its elasticity also stands in close connection with the same.

The method of ribbing the sounding-board has not been supplanted by any other during all the time in which pianos have been built. Those pianoforte makers who have studied the history of the piano, and have observed the history of the sounding-board for years, will understand that it is useless to try to substitute other means for the ribs and thereby better the ability of resonance in the sounding-board. Let us select from among the old methods one which has of late been advertised as a new invention. Two boards are so glued together that their grain crosses either in an acute or right angle, and the four rims of the board glued are then pointed in a like manner as the ribs on the sounding-board. A certain stiffness of the sounding-board may be obtained by such a method; but surely it holds no special property for the elasticity of the board. A better method to construct sounding-boards without ribbing is found in so working a thick board that the same forms a continuous undulatory figure at its cross end. The sounding-board bridges are placed upon the highest points of these waves or undulations, much like sea gulls on the ocean's waves.

A rational idea to construct ribless sounding-boards, which has arisen from time to time and may yet be heard of again, consists in constructing pianoforte sounding-boards according to the patterns of stringed instruments. Such boards were called violin or violoncello sounding-boards. Although the idea is well worthy to be carried out in the pianoforte, it is impossible to do so faultlessly on account of the spreading and curvature of the sounding-board bridges on the large surface of the sounding-board. We mention another curious arrangement, which has no claim to novelty but which was proclaimed as a recent invention in the Chicago ***Musical Times*** of January 12th, 1898. The paper reads as follows:—

"A firm at Hamburg has recently patented an improved sounding-board, composed of double layers on spruce fir, connected by ribs which run the whole length of the piano, dividing the double sound-board into narrow chambers or canals, acting as resonators, in which the air takes up the vibrations of the strings and communicates with the outer air through sound-holes made in the upper sound-board. This contrivance has been found to greatly increase the resonance power of the piano."

No set law can be given for the number of ribs on the sounding-board, for all depends upon the size and thickness of the sounding-*board*, upon the thickness of the ribs and the position in which they are placed on the sounding-board; hereby there exist various methods which may result successfully. The method illustrated in Fig. 11 is prevalent at present for the position of the sounding-board and ribs.

Great uncertainty prevails as yet about the elasticity of the sounding-board in conjunction with its vibratory forms, therefore let us discuss the subject.

It is destination, so to say, that every outward movement of a sounding body must swing in an undulating form just as soon as the elasticity will permit, and that the best tone can then be produced. It is our aim to ascertain why string and sounding-board produce the best tones with such a vibratory form. Step into a hall with me where people are dancing. We find the people dancing in a certain rhythmic motion which sets the floor of the hall in wave formed vibrations. Suppose a waltz is being danced, and that all participants are excellent dancers. Wherein does the dexterity of their dancing lie? In the pleasing, graceful form of movement not alone of feet and limbs, but of each separate part of the body. Every line in the form of the movement of the body of the dancer is a perfect, undulatory line; and the undulatory line must be found in the movements of the dancer and the floor of the room. Our piano is the dancing hall, the strings are the dancers, and the sounding-board is the floor of the hall. If the strings swing in correct undulating form, this form of movement must transmit itself to the sounding-board. If, however, the board be too stiff, elastic, &c., the dancers soon tire, giving rise to that uncertainty in the form of movement which every one may have experienced

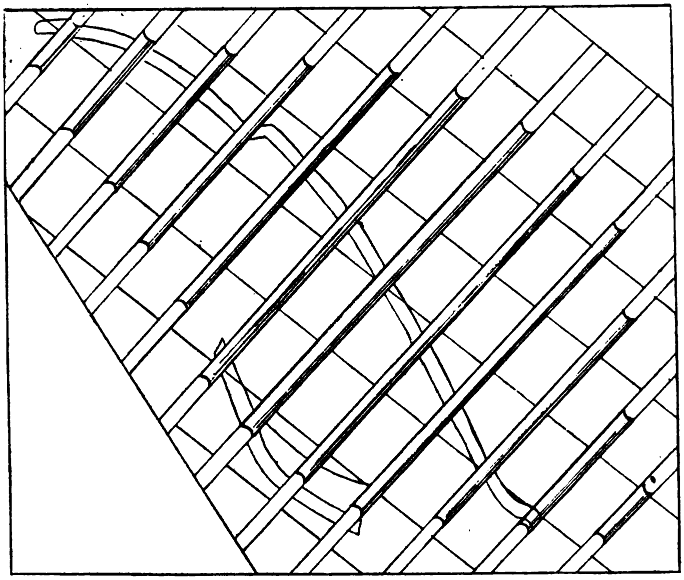

Fig 11.

in his first attempts to dance. The outward form of motion which we perceive comes from the exertion of the inner being: every fibre, every nerve has to regulate its activity to the form of the outer movement of the body, and not even the body's molecules are exempt, herefrom. This is the view of the fact when the strings swing with several waves in undulatory form; the counterpart is when a row of schooled gymnasts practise jumping. The floor is set in motion too, but it can only be a rising and sinking,—it is like the movement which we perceive in a piano string when it works in its entirety, with one full wave. If some one wishes to practise jumping, he chooses a very elastic floor; after the same principles, we choose an elastic sound-board if we desire the strings of a piano to swing with one full wave. If we are in a carriage which swings in this manner while in motion, the jarring of the movement will by no means affect us agreeably. Such phenomena with sound affect the perception of the ear in similar manner. When Pellisov, (whom Dr. Paul supposes to be the same person as Dr. Schafhaeutl) says that, according to his observations, the sounding-board best serves the purpose the less it moves as a whole, or in its entirety, he is fully right. We now acknowledge the necessity of an undulating movement of the strings and sounding-board, and comprehend that we must be directed by the laws which permit a correct one. We will try to elucidate, by means of the resonant body of a bell, the divisions of the body for the swingings of the undulatory form.

As soon as a bell is agitated, it divides itself into four certain fields, which run perpendicularly from the crown or top of the bell and are bounded by certain lines of rest. Two opposite fields approach as the remaining two diverge during the bell's swinging. To simplify explanation, let us apply the cardinal points to the four fields in the mantel of the bell. As the prongs of a tuning fork must vibrate toward and from each other, because they stand opposite each other, just so are the two opposite fields of a bell forced to swing toward and from each other, so that at the moment when the south end of the bell swings towards the north end the latter must swing toward the south end. When north and south fields approach each other, the east and west ends are naturally forced out,—that is, they diverge.

Imagine the bell cut lengthwise in one of the lines of rest while it is in the position above described and laid out on a level; it would then be in an undulatory form. A circle cut out of the circumference of the bell and laid out in the same manner would appear to us like a swinging piano string with four waves and five nodes.

The sounding-board bridge is formed according to the position of the strings and according to their lengths. We find, for example, the position of the strings in a square piano differing from that of the strings in upright and grand pianos. and therefore the form of the bridge in a square piano is decidedly different from the form of a grand or an upright piano's sounding-board bridge.

The proportions of height and width of the bridge are arranged more according to the bearing power of the ribbing. It may be observed that in pianos where the ribs run in the direction of the sounding-board bridge—that is, where they are employed to bear but little—the proportion of the sounding-board bridge in thickness and width is an exceedingly great one. One piano among others which crossed my observation had the ribbing of the board running parallel to the wrest plank edge, and the sounding-board almost hanging free in the instrument. The height of the sounding-board bridge in this piano was 5 c.m., and it was 4 c.m. wide. Generally, with well chosen position for the ribs respecting their employment as bearers, a bridge height of 2·3 c.m. and a bridge width of from 2·6 to 3 c.m., will suffice.

Special benefit cannot be derived for the instrument in which the bridge has to aid in producing a certain stiffness of the sounding-board. The disadvantages, however, which a high bridge facilitates are too evident to be disputed. First, since the wooden back lies further from the strings than it does when a low bridge is used, the drawing power of the strings demands a far greater bearing power from the iron frame; secondly, since the ribs do not possess sufficient bearing power, there is a greater possibility for a sinking of the sounding-board, whereby under certain circumstances the power of the instrument to remain in tune for a time suffers much.

Some manufacturers in America construct the sounding-board bridge of from seven to nine thicknesses of wood, which are curved to the shape of the bridge and glued together. If thereby one thickness runs perpendicularly so that the cross end of the wood touches the sounding-board, the next thickness runs lengthwise in the direction of its grain or fibres along the bridge, and so the wood thicknesses change, so that first long wood and then cross end wood touches the sounding-board. The top of the bridge is then covered with a 6 m.m. to 7 m.m. thick board, into which the bridge pins are placed. The bridge, consisting of several thicknesses of glued wood, possesses no specially valuable properties, and in many respects the plain wooden bridge is preferable to it. Maple and beech are excellent woods for bridges.

There are several valuable properties of the sounding-board still to discuss which more or less render the same important service in its activity. To these properties belongs specially a suitable straining of the sounding-board, a straining through which the elasticity of the board is raised and an undulatory movement facilitated. It is not always the case that an arched sounding-board works better than a flat one. From among the many devices which will arch the board one may here be mentioned consisting of two bow shaped laths glued for a rib. Through placing such ribs under the sounding-board, the sounding-board is arched, which however does not in the least influence the inner strain of the sounding-board, but weakens its elasticity considerably through the exceeding stiffness of these ribs.

A most satisfactory result is gained by the process explained in the following lines. Before the bridge is glued to it, the sounding-board is placed a whole day into a specially hot and dry place (usually a steam box); and, while it is in a hot and shrunken state, either the ribs are glued in their order to it, or the bridges may be glued on it first. The sounding-board may have a level layer under it. If the bridges are glued on first, the sounding-board must again be exposed to the dry heat. Proceed likewise in gluing the sounding-board to the linings of the back. The sounding-board will stretch again after a while, and through this there remains a certain strain in the sounding-board which may well aid it in its elastic movements. At any rate, this treatment of sounding-boards is always productive of a special intensity of tone. Generally, sounding-boards thus treated show marked signs of a compression of the wood: the grain swells out of the before carefully levelled surface of the sounding-board,—a certain sign that there has been an expansion in its wood.

The sounding-board has the property to sink a little as soon as the strings of the piano are tightly drawn. (With a well constructed sounding-board and good string position, this sinking will not exceed three millimètres.) Therefore the linings upon which the sounding-board is glued should be sloping at their outer edges, thus causing the board upon being glued to them to assume an arched form; which however, in the middle of the sounding-board or the highest point, should not be more than twelve millimètres high.

Of the many little tricks tried with the resonant wood or the board, whereby each manufacturer represents his own opinion and method, one piece of quackery may here be mentioned. It is the so-called "impregnation" of wood. The firm of Wachtl & Bleyer mention (in the documents referred to in Chapter VIII.) a treatment by which they impregnated their sounding-board. They write as follows: "The wood must be steamed for forty-eight hours before it is placed in the kiln. The hot steam arising from salt water penetrates all the pores of the wood, forcing out all the resin, which appears in brown globules on the surface. This process renders sounding-boards not alone more durable but better from an acoustic standpoint."

I must admit that for some time I was an ardent "impregnator," not alone using salt, sulphur, and steel water from the wells of Oeynhausen, Eilsen, and Pyrmont, but even trying acids for wood impregnation. After discovering that this process destroyed more than it remedied, I turned my attention to drying wood through the influence of sunlight to magnetism. The sounding-boards for this purpose were worked out almost to their required thickness, and then placed into the direct sunbeams. I spared neither pains nor trouble to place twelve sounding-boards daily during the months of June, July, and August, into the direct sun rays, carefully avoiding dampness in any form. The surfaces of the boards became tanned a deep brown from the effects of the sun, and of a wrinkled appearance imparted by the exuded resin drops. Although I had promised myself much for tone quality from these sounding-boards, they did not repay all my labour and care, as they were no better than the naturally dried ones. Six or seven years of natural drying under cover and sufficiently separated to avoid a moldering of the wood (that is, so that it receives enough air), produces the most satisfaction, and is preferable to all artificial preparations of wood for sounding-boards.

Chapter X.

Cast iron frames of pianos.

There exists scarcely any other profession dependent upon so many branch trades as pianoforte making. It is evident, therefore, that the progress of piano making during the past century proceeded chiefly from these bye-trades. It would, for example, have been impossible to gain the great improvement in quality and quantity of tone in the piano had not an improvement in the absolute solidity of music wire preceded it. This considerable fulness of tone in the piano was not alone gained by an enlarged proportion of thickness in the strings, but also and chiefly by an increased molecular tension. Through the increase in the tension of the strings, the customary wood work became too weak; and, as the drawing power of the strings increased to such an extent that in modern pianos it stands on an average of 36 000 pounds, piano makers were forced to adopt the help of the art of iron casting despite all enmity toward the cast iron frame. If the iron frame has triumphantly entered the piano factories of all nations, it is because its use is absolutely necessary for the durability of the piano.

Glancing back to the year 1811, at the accounts of the firm of Wachtl & Bleyer of Vienna, treating of the durability of the pianos in that day and the amount of pulling power of the strings of their instruments, we comprehend that piano makers were forced from time to time to seek for means to promote the durability of the piano. The before mentioned firm gave the following explanation: "If a case is built in the usual way—namely, with a massive back post – one finds after the expiration of about half a year, in tearing out the sounding-board, that, through the strain of the strings (which equals about ninety centner), all posts have pressed a line deep into the incasement and are entirely loose. Well, loose posts in the backs of our present "wire boxes" are found more frequently than heretofore; and, if the cast iron frame would not support the sickly skeleton awhile, so wretched frame work could find no application in piano construction.

Not alone interesting but also instructive for the present piano makers are the glances back into the history of the piano. The following, which the firm of Wachtl & Bleyer announced with pride about ninety years ago, is also of importance to the present piano construction. The announcement of the firm reads as follows: "Besides, our pianos have only three mutations, — forte, buff stop or harp pedal *(Lautenzug)*, and shifting of the action. On request we may add the bassoon and the æolian harp,—but, drum and cymbals, never!" These are good instructions for correcting errors which have again arisen in piano construction. Like the firm of Wachtl & Bleyer, throw out the ancient, renewed, and repatented "clim-bim," for such rattle work does not belong to a piano.

The ninety centner before mentioned, with which the pianos of the firm of Wachtl & Bleyer were burdened through the pulling of the strings, are equal to about ten thousand American pounds, and thus the pulling power of the strings in pianos of our day is just about four times as great. The renowned Chladni states of English pianos of the year 1824 that W. Stodart (at that time piano maker to the royal family) received a patent for metal tubes, which were placed over the strings of his compensations-pianoforte, and were especially intended to counteract the pulling power of the strings. Stodart states that the pulling power of his pianos at that time, with a range of six octaves, was thirteen thousand pounds. At about the middle of the nineteenth century pianos were given an average burdening, through the pulling of the strings, which in a grand piano was about twenty-eight thousand pounds, and in a square (which possessed fewer strings for the notes with single strings than a grand piano) about twenty thousand pounds.

In order to give the hitch pins a firmer hold than they could possibly have in wood with the strain of the strings, iron plates of sheet iron were generally used in those times. Iron bars or the before mentioned metal tubes were connected with the iron plate and wrest plank to counteract the pulling power of the strings. These connected supports for the pulling of the strings were not rarely loosened from their fastenings.

The cast iron frame gave the piano its full stability. The cast iron frame takes the greater part of the burden caused by the drawing of the strings from the back upon its massive iron bars, and thereby allows the sounding-board (which stands in close connection with the back) to execute its work unrestrainedly. Despite all stability given to the piano by the cast iron frame, it has by no means reached the stage of absolute stability of tuning; and, after many trials, the conclusion has been formed that it is impossible ever to gain this point in the piano· Thus, to come a little nearer to the desired stability of tuning, back, wrest plank, and iron frame were made of cast iron, and the result was an excessively heavy piano with a decidedly wirey tone.

Judging from historical dates, the ingenious Seb. Erard* made the first important attempts to give his pianos a greater stability of tuning through iron frames. The claim of first having employed cast iron frames for pianos belongs to the Americans, and especially to Alphæus Babcock (at that time an inhabitant of Boston and later on of Philadelphia), who, having received the first United States patent for a metal frame complete, with hitch pins section made in one casting (December 17th, 1825), well deserves to be mentioned here. In Spillane's "History of the American Pianoforte" (chap. 9) may be found all the details concerning the desire of others to deprive Babcock of his claim as inventor, especially of a German, Conrad Mayer, born in Marburg, and who emigrated to Baltimore in 1819. Spillane writes about the cast iron frame as follows: "While defending Babcock's position as an inventor, it is not claimed

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* Seb. Erard born at Strassburg, Elsas, April 5th, 1752; died in his palace, La Muette, near Paris, August 5th, 1831.

that his frame was entirely acceptable from a modern standpoint, or entitled to be regarded as an anticipation of the plate introduced by Chickering in 1837,“ &c.

Jonas Chickering and other Bostonian piano makers were the first pioneers for the modern cast iron frame in the piano. Till 1855 the cast iron frame was not extensively used even in America, and it had many opponents, especially among the piano makers of New York. The reason for this may be sought in the fact that iron frames cast in earlier years, even those cast in America, were constructed so massively that many a disadvantage was caused to the sound production of the instrument by their excessive heaviness. Then the casting was of a coarse and brittle structure; so that, despite the massiveness of the frame, one might expect it to burst at any time.

The time came when American pianos contained artistic cast iron frames. It had been observed that, with the greater stability given to the piano by the cast iron frame, the tension of the strings had to be increased; and with this the proportions of the sounding-board had to be enlarged, in addition to which a hammer (very tightly trimmed with felt) was used, — a hammer for the trimming of which specially strong machines were constructed. The fulness of tone in the American pianos now astonished the piano builders of all other countries.

Although piano construction in foreign lands is arranged according to the American system, especially among the Germans (who have not hesitated to send their sons to America to study piano making), it is safe to assert that American cast iron frames are superior to all others in quality and artistic construction. The arched forms of the plates between the iron bars, which stand out from the rims of the frame much like the form of a violin, render a sufficient resisting power against the drawing of the strings possible with a casting only 7 m.m. thick.

Some piano builders have lately been thinking much of aluminum frames for pianos. Aluminum is said to be three times lighter than iron, but it is very doubtful whether the properties of aluminum are superior to those of cast iron or not as regards its use for the purpose of metal frames in pianos.

Trials have been made with aluminum for metal plates in pianos. Thus, a piano firm in Heilbron is said to have exhibited a piano at the Theatrical and Musical Exhibition of Vienna, in 1892, containing an aluminum instead of the ordinary cast iron frame.

Let us faithfully and carefully guard the cast iron frame, for it is not likely that another metal will be found which during the process of casting will shrink so little as does cast iron. With 97 c.m., cast iron shrinks only about 1 c.m., so that the shrinking quotient is 1·0104. What other metal could replace cast iron with so small a shrinking quotient? Yet even this slight shrinking of cast iron so changes the form and proportions of the iron frame that the scale maker who in making the wooden model has not calculated with the shrinking quotient of cast iron has to alter the stringing scale according to the form and proportions of the iron frame. Hereby the carefully calculated and worked plan of the stringing scale is lost, and the scale maker is compelled to adopt dimensions in the scale which he would otherwise have refused to accept.

The first cast iron frame which comes from the mould made after the wooden model is kept in the iron foundry to be used as a model for casting other frames to be used in pianos. Therefore, in making the wooden model, a double shrinking quotient must be employed in the calculation. If iron, in shrinking once, diminishes from 97 c.m. to 96 c.m., it will diminish from 97 c.m. down to 95 cm. in shrinking twice; therefore the double shrinking quotient is 97 : 95 = 1·02.

After we have drawn the shape of the cast iron frame in the stringing scale, we must take the trouble to make a separate drawing for the wooden model from the drawing of the original frame, thereby calculating with a double shrinking quotient. In Fig. 12 we find a sketch of an iron frame. In the separate drawing the lines *a-b* and *a-h* must be considered stable, making only the difference that the points *b* and *h* are further from point *a* in lengthening the lines *a-b* and *a-h*. In the sketch the point *b* is 12·6 c.m. from point *a*, and we must now make it lie 12·6 × 1·02 = 12·852 c.m. in the lengthened line *a-b*. Just so must we treat point *h* in the perpendicular line *a-h*. The point *h* is 5·4 c.m. from point *a*, but must be 5·4 × 1·02 = 5·508 c.m. from point *a* in the lengthened line *a-h*.

If the lines *a-b* and *a-h* are to be looked upon as stable in the separate drawing for the wooden model, all other lines of the original drawing are shifted in transferring them to the separate drawing. This we find done as an example in the

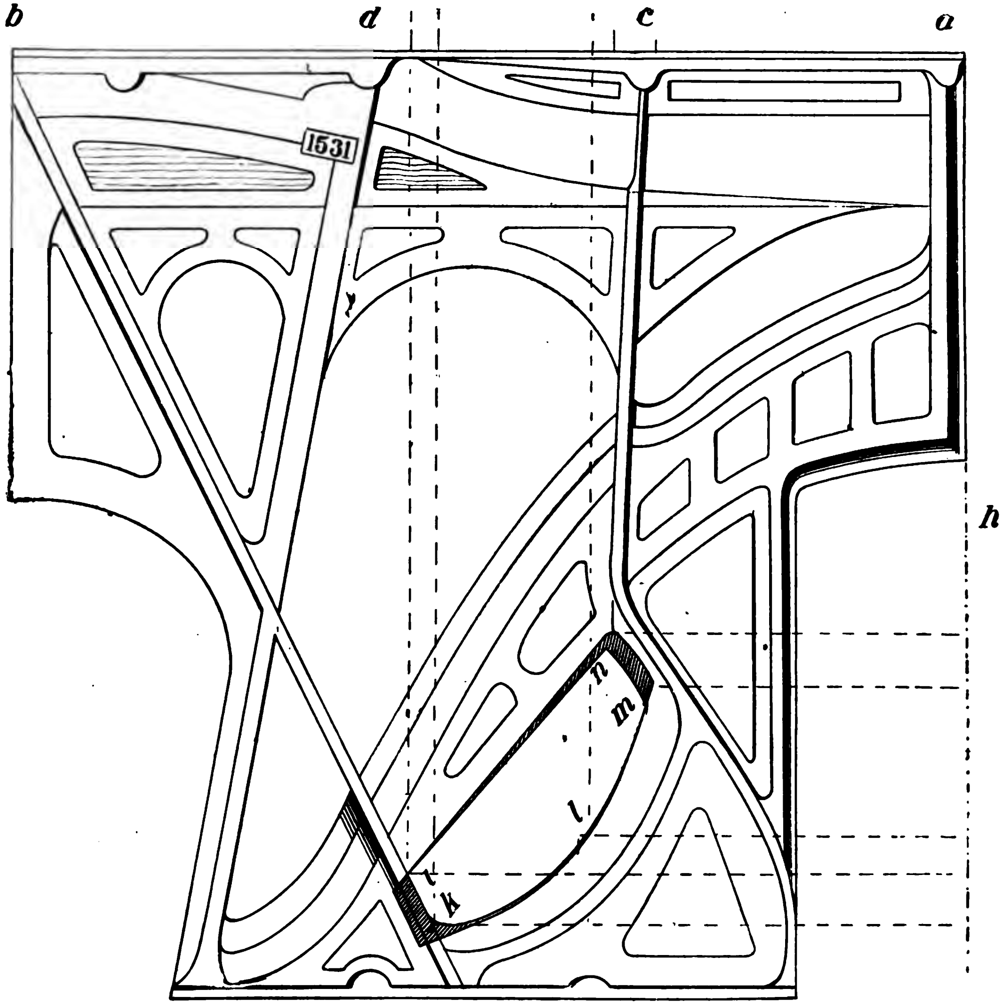

Fig. 12.

sketch Fig. 12, in that part of the drawing which represents the opening for placing the bass bridge. While devoting our attention to the method of calculation for this part, all details as to the method of calculation for the completion of the separate drawing will thereby be explained.

A straight line can be drawn as soon as its extremities are fixed. Thus, if we wish to draw the line *i-n* in the separate drawing, we must try to find the point *i* by means of the stable line *a-b*. Drawing a dotted line from point *i* at right angles to the line *a-b*, we find the point *i* in the diagonal line *i-d* 10·9 c.m. from the line *a-b*. The distance of point *i* from the line *a-b* is 10·9 c.m. × 1·02 = 11·118 c.m. in the separate drawing. Just as we placed the point *i* from the line *a-b*, we must now place it from the line *a-h*. If through the point *i* which was found by calculation we draw a dotted line at right angles to the line *a-h*, the point for the separate drawing will be situated in this line; and, as the point *i* in the original drawing is 7·4 c.m. from the line *a-h*, we must place point *i* of the separate drawing 7·4 cm. × 1·02 = 7·548 c.m. from the line *a-h*.

After we have placed the point *n* in the separate drawing by the same way of calculation, we can draw the line between the points *i* and *n*. In determining a curved line, we must find the required number of points in the curved line of the original drawing and transfer them to the separate drawing by the above given method calculation. We then connect the several points, as was done in the sketch with the line *m-l-k*. The shaded part of the opening in the sketch gives us an idea of the change in form which exists between the wooden model and the cast iron frame ready for use in the piano. We perceive that in places the lines of the separate drawing cover those of the original, while in another part of the opening the lines of the two drawings deviate considerably.

After the scale drawer has transferred all lines to the separate drawing for the wooden model, he may employ all his skill in giving a pleasing appearance to the iron frame, for cast iron may be ornamental besides being a necessity to help bear the drawing power of the strings.

For the wooden model which is used to form the cast iron frame, quadrate white pine is preferable to other woods. This wood in its specific weight is sixteen times lighter than cast iron, the specific weight of which is 7·20; that of dry white pine is 0·45. According to this, the cast iron frame should be sixteen times heavier than the model of pine wood. Many trials, however, have proved that the iron frame may be reckoned as being on an average eighteen or nineteen times heavier than the wooden model, provided that the latter is made of well dried white pine. Most likely this greater weight is caused by the double moulding.

Chapter XI.

Piano hammer covering.

The material used in pianoforte making nowhere shows want of substantiality so much as does the material with which piano hammers are covered. From the earliest stages of pianoforte making to the present, it was the constant care of pianoforte makers to obtain, not alone a well worked hammer, but also a good material for covering the same. The material used to cover hammers, and which comes in contact with the strings of the instrument during playing, gives no sound; but it has considerable influence on the sound character of the instrument, and is capable of suppressing or bringing out the best properties of the piano as regards sound effect.

Glancing through the history of pianoforte making, we find that piano hammers were not always covered with felt. Going still further back to the clavecin (or clavicymbal, as it is often called), we find that the agitators of the strings were feather quills of goose or ostrich feathers. Sometimes whalebone was used; but, above all, raven quills saturated with olive oil were given the preference as agitators for the strings. About the middle of the eighteenth century, the organ builder Johann Christoph (of Anspach, Germany) used brass pins instead of raven quills. These brass pins produced a stronger sound and were more durable than the quills. In 1768 Paschel Taskin, the instrument maker and inspector of the instruments of the royal orchestra in Paris, used pieces of stiff buff leather instead of raven quills. According to Abt Vogler's account, a surprising fulness of sound was thus obtained from the bass strings.

Meanwhile the invention of the hammer action laid the bassis for pianoforte making. Judging from Dr. Oscar Paul's "Geschichte des Claviers", it was the German organist Christoph

Gottlieb Schroeter (born August 10th, 1699, at Hohenstein, Saxony), who invented the hammer action. Schroeter asserts that he invented hammers to strike the strings in 1717; and, while manfully defending his right as the inventor, he declares that he carried a model of his hammer action to the royal palace at Dresden, on February 11th, 1721, in the morning between eight and nine o'clock, and that his royal majesty decided that a skilled instrument maker should build an instrument under Schroeter's direction with hammer action, in which the hammers strike the strings from underneath. Judging from Schroeter's assertions, he had to contend with opposition, caused by members of the royal family. Schroeter left Dresden, and consequently the instrument was not constructed, nor was the model returned to its owner. Schroeter says that he covered the hammers of his model with leather.*

The method of covering the hammers of the pianoforte with buckskin was generally adopted. In the year 1806 John Antes publicly announced his attempts to cover pianoforte hammers with German tinder. He asserts that this tinder had for five years done good service in his pianoforte. Despite the skill obtained by constant practice and exercise in covering hammers with leather, despite the excellent preparation of buckskin for the purpose of covering hammers, the method of covering hammers with leather never gave full satisfaction. John Antes says, in recommending German tinder, that leather when beaten becomes hard. Continued playing creates the same result. As sweet and mellow as the tone of an instrument may be when it leaves the master's hand, it hardens in the same degree as the leather, and will in time be so sharp and piercing that the hammers must be recovered.

German tinder does not seem to have found much favour, and it remained for the ingenious piano maker Pape of Paris

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* Dr. Aloys Obrich writes against the invention of Schroeter in the "Zeitschrift für Instrumentenbau" Jan. 11th, 1904 that at the time of Schroeter's invention, Cristofori built pianoforte grands with a mechanism which surpassed every thing which Schroeter ever published. Dr. Aloys Obrich refers to Hipkins, an authority whose scientific thoroughness stands above all doubt.

(born in Hanover, Germany) to find the material to be used in the future for covering piano hammers. This material, of which Pape made the first use for covering hammers was felt. The durability of felt at that time could most certainly not compare with that of leather; and, although Pape's method (covering hammers with felt) was soon extensively adopted, many felt hammers were given an extra covering of buckskin for the sake of durability. The wondrous sound effect created when felt comes in direct contact with the strings of an instrument during playing of the same caused the evil of quick wear to be overlooked, the more so when felt was made firmer and more capable of repelling the cutting of the strings. The use of leather for capping felt hammers became more and more unusual, and is now entirely out of vogue, being applied only in repairing.

When first hammers were covered with felt, a strip of this material prepared for a special hammer was laid by hand, and with the aid of pincers, upon the wooden moulding of the hammer and fastened with glue. This method was followed for many years, being frequently met with in instruments made in the sixties of the last century. During this time, however, successful attempts were made to cover hammers in full sets by means of a machine specially invented for this purpose. One important improvement in felt hammers coming from such machines was in a more even distribution of the firmness and tension of the felt from the bass to the treble end. This peculiarity in the make of the hammers was perceptible in the evenness of the separate degrees of the scale; and, as such evenness would hardly be attained with hand made hammers, the use of the hammer covering machine soon spread.

The machine was improved more and more, so that felt manufacturers soon became aware of the necessity of their supporting the piano manufacturers in their efforts. Especially in America, where the piano trade flourished, extraordinarily thick and well made felt was in great demand. Through the persistent incitement of the best piano manufacturers, and through the zeal of the firm of Alfred Dolge of New York always to produce the best material for the making of pianos, this firm was successful in making felt sheets of extraordinary dimensions, and they displayed the same at the Vienna Exhibition of 1873. These sheets measured 92 by 110 c.m., and were 4 c.m. thick at the bass end, tapering to 0·4 c.m. at the treble end, each sheet weighing 22 lb. Occasionally such sets are now used for grand piano hammers, but then only without the customary underfelt.

The method of making hammers without underfelt was extensively followed for awhile in America. Of late, however, manufacturers have reverted to the underfelt method for piano hammers. The felt sheets used as top felt for hammers at present measure 92 by 110 c.m., and weigh from 10 lb. to 16 lb. The underfelt for the hammers is proportioned to correspond with the top felt, and rarely reaches to the last treble hammers. It is to be understood that the writer speaks only of first class quality, leaving all trash unregarded.

Making a comparison between felt sheets of to-day and those of former years used for hand work, we can estimate the different stages in the progress of piano construction. The felt sheets used for covering hammers by hand in the sixties of the last century measured 92 by 136 c.m., weighed from 8 lb. to 9 lb., and were from 0·6 to 0·8 c.m. thick at the bass end tapering to 0·2 c.m. at the treble end. The writer has no evidence as to the proportions of felt sheets which were used before this time; however, a comparison can be made from the felt hammers as they are found in the pianofortes of this early period. The force with which the hammers of different periods struck the strings can be estimated by the weight of the hammer. The tiny hammer found in an old English action, when compared with the hammer of a modern grand, reminds us of a hammer from a child's tool chest compared with that in the brawny hands of a smith. The felt mass of the present piano hammer is compressed at the hammer's forehead to two thirds its thickness. Supposing that no history of the pianoforte had been written, a perfect one could be compiled after comparing the proportions of felt sheets from the different periods.

Specially strong and surely working hammer covering machines had to be invented and built so that useful hammers might be made of felt sheets weighing 16 lb.

It is erroneous to imagine that the highest possible stage in the make of piano hammers has been reached. We see in Fig. 14 a peculiar hammer as yet little known to pianoforte makers. This felt hammer is superior to the one as seen in Fig. 15, excelling in the production of a full tone and resistance against wear of the felt.

With the hammer as represented in Fig. 15, which is in use at present, the form of the hammer flattens through continual striking against the strings; the felt mass loosens more and more thereby, for it has no support as has the felt of the hammer represented in Fig. 14. The felt loses in resistance against the cutting of the strings through this flattening. Some piano makers tried to remedy this evil by saturating the lower and upper parts of the felt hammer with shellac, whereby of course the portion which comes in direct contact with the strings was excepted. It is self evident that this saturation of the felt by hardening substances could not hold the felt hammer together as well as the wooden clamp of a hammer like Fig. 14.

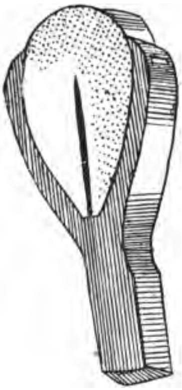


Fig. 14.

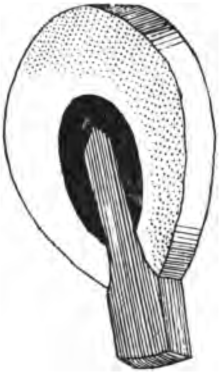


Fig. 15.

A German-American, John Ammon, conceived the idea that he could economise in the use of felt if, instead of putting the felt over the wooden moulding, the same were glued directly together—that is, to its own sides—without the moulding. Such a hammer would consist of a separate felt hammer head and a separate wooden neck into which the hammer shank is adjusted. The connection between the felt head and wooden neck is made by means of a V shaped cut in the latter, which clasps the head. This combination is so incomplete that the hammers (especially the treble) lose their firm hold in the V split at the first violent blow which they deal on the strings, and thereby become useless. John Ammon received the American patent No 504.192, August 29th, 1893.

Alfred Dolge—who in Dolgeville made the manufacturing of felts and piano hammers a real study—took a different and practicable view of Ammon's piano hammer idea, realising that through such a hammer no economy in felt but the long desired firmness of the hammer heads could be acquired. The firm of Alfred Dolge & Son of New York spared neither trouble nor pecuniary sacrifices to carry out the experiments (which took up some years' time), and at last, by means of excellent machinery, they had a hammer perfectly useable in every way to offer to piano manufacturers.

The wood which is to hold the felt (Fig. 14) is softened by means of steam baths, and is then forced into a certain form by machinery specially constructed for this purpose. Should the attempt be made to saw out the wood in the desired form of the hammer, the brittle end wood could not be avoided in the clamp shaped moulding. As it is, the long fibres of the wood assume the form of the clamp. The felt also, before it is glued into the clamp (which, by the way, is likewise done by machine), is shaped to fit into the same. It is evident that these hammers are more expensive to manufacture than the old felt hammers, and it is therefore likely that only the best manufacturers will adopt them at first.

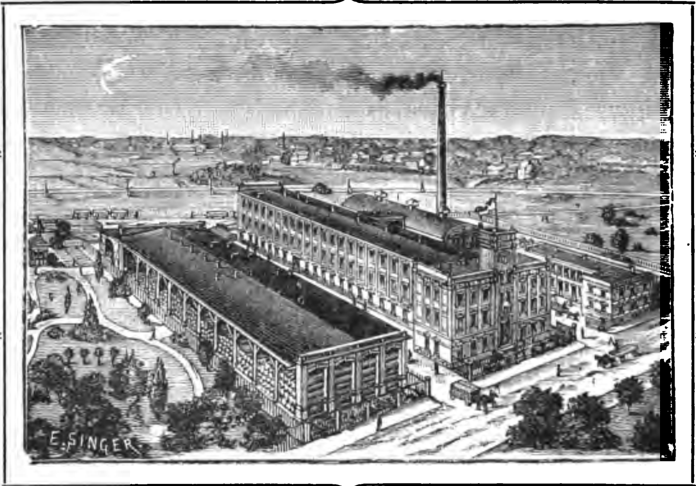
The wool ,used for hammer felts consists of a mixture of Silesian, Cape, and Texas wool. These three species of wool are specially well adapted for felting, but are not as fine and soft as wool from the Australian merino sheep. The wool of these sheep, being possessed of less elastic power and not so well adapted for felting, is specially well adapted for piano damper felt.

H. F. Flemming

MANUFACTURER OF

Grands and Upright Piano Actions.

Leipzig-Leutzsch—Germany.



First class material, specially constructed machinery and trained workmen guarantee the goodness of

Flemming Piano Actions.

The Flemming Piano Actions are used in first class Pianos.
The Flemming Piano Actions have stood the test of all climates.

Chapter XII.

Piano actions.

The construction of various kinds of pianoforte actions has for many years been considered a special branch of pianoforte making, and has been treated accordingly. With few exceptions, pianoforte manufacturers procure their supply of actions and also of keys from factories established for the purpose. This arrangement has proved beneficial to pianoforte making, for there is hardly a pianoforte maker to be found who is so proficient in all branches of pianoforte making that he may boast of mastership in them all. He must, however, have a knowledge of the nature of the action and of the purpose of its parts; he must study the mechanical part of the instrument and acquaint himself exactly with the cause and effect of the action. We may well leave the construction of the action in all its details to our tried action manufacturers, and concern ourselves only with the fitting of the action into the pianoforte.

With the pianos of the present day, we have two kinds of actions with which to deal: one kind belongs to the grand and the other to upright pianos. The upright has supplanted the once beloved square piano, which will however be reverently remembered as often as a history of the piano is written. The nature of the action has been arranged according to the position of the strings, which lie horizontally in grand and run perpendicularly in upright pianos. The repeating system of Sebastian Erard, which he published in 1826, is still used with preference for grand actions. In the course of time much has been altered in the original grand action as constructed by Erard, and improved, especially for the elasticity of the hammer shank. It was Henri Herz of Paris (the same Herz who was noted as a pianist on both sides of the ocean at that time) who in keeping with Erard's principles simplified the action. On the whole, we find it with few exceptions in mostly the same form in the grand pianos of to-day.

Although the zeal of manufacturers was awakened by the principles of the Erard action, so that many repeating actions were made in the course of time, yet none of them have supplanted the Erard-Herz action. Lately many improvements have been made on the repeating spring of the action. Be it remarked that with the earlier Erard grand action the dampers were pressed against the strings from underneath the same by means of springs, thus providing for the damping of the strings. In modern grand pianos the dampers for damping the strings act from over the same; and, instead of regulating a close fitting of the dampers on the strings by means of springs, it is now done by the weight of the damper heads, aided by little round pieces of lead which are fastened in the damper levers.

In grand pianos, the difference in the position of the dampers alters nothing in the action parts; whereas in upright pianos we distinguish two classes of actions—the overdamper and the underdamper action—from the position of the dampers. The overdamper action bears its name because it acts on the strings from over the hammer heads, while the underdamper action executes its work from under the same. With the general endeavour more and more to increase the volume of tone, the use of the overdamper action is growing less frequent, and despite the many advantages it offers must submit its place to the underdamper action. In America underdamper actions are exclusively used, whereas in Germany for instance more than half the upright pianos are supplied with overdamper actions. Every piano maker is well enough acquainted with the actions in general use, so that an exact description of the separate parts is not necessary. Let us give ample space to that which may be said of correctly fitting the action into the piano.

First, we must make a model of the action we intend to use, or borrow one of the action maker who usually has such models on hand. In placing the action, care must be taken to set it at a correct distance from the strings. This distance in upright pianos depends especially upon the position of the dampers: an action with overdampers may be placed much nearer the strings than one with underdampers. The length of the hammer heads and the position of the holes for receiving the hammer shanks must be arranged according to the distance of the action from the strings. The length of the hammer shank should be so arranged that the distance from the turning point of the hammer butt in its flange to the middle of the hammer head is 13 c.m. This is not alone determining for uprights, but also for grand pianos.

In setting an upright piano action, the finisher must take care that the returning of the hammer is prompt, for nothing hinders the repeating of the action more than does a slack return of the hammers to their original position. For this reason it is expedient that the hammer, when it touches the strings, be given an over-weight towards the hammer rail by having the hammer shank at the hammer butt 4 m.m. nearer the strings than at its upper end at the hammer head.

The distance of the hammer's blow in grand and upright pianos is 5 c.m. in the bass and 4·8 c.m. in the treble. The hammer must stand at right angles to the direction in which the strings run when it touches the same in order that its blow may be steady and correct. A deviation in the position of the hammer from this right angle makes the blow of the hammer so soon as it touches the strings slippery, and such is noticeable in the sound quality. If the hammer head stands at right angles to the direction in which the strings run, it forms an acute angle with the hammer shank, the latter being nearer the strings at the hammer butt than at the hammer head.

In the grand piano action, the returning of the hammer to its position of rest is already secured through the horizontal position of the hammer shank; and, so that the blow of the hammer upon the strings may be properly executed, the hammer shank when the hammer touches the strings lies in a horizontal position, parallel to the strings and under the same, whereby the hammer head is at right angles to the hammer shank.

With upright pianos, the hammer when it has gone one third of its way from the strings back to the hammer rail must be caught by the back check on the back stop (which is attached to the hammer butt), and this not alone for the sake of a pleasant touch but also to secure a repeating of the action. With grand pianos having the customary action, the hammer may be caught by the back check at a little less than one third of its way back to the position of rest, for such is requisite for the repeating of the action. We may consider all these statements general rules for setting actions into different pianos.

We will now treat of the different turning points of several parts of the action the fastening of which is left by action makers to pianoforte makers. At first we will ascertain in which place the point of balance of the key shall be situated. We cannot do this without a certain division of the key into a fore and back lever. We must find the proportionate length of these two levers to each other, through which the point of the key's balance is determined, from the proportion of the raising of the key at the point where the back lever lifts the action, and from the established depth of touch of the key attributed to the fore lever. The height to which the back lever of the key rises may differ, for it depends upon the length of the jack (Fig. 16), so that the longer the jack the shorter the distance to which the back lever of the key rises. Hereby the extent of the distance which the jack goes under the hammer knuckle is also concerned. For example, in Figs. 17 and 18 we find two hammer butts with different kinds of knuckles. We perceive that the jack can much sooner wend its way to liberate itself under a knuckle as seen in Fig. 18 than it can under a knuckle of the hammer butt as in Fig. 17. It is self evident that this is noticeable in the height to which the back lever of the key rises. Just such difference is noticeable if the tail end of the jack is made longer or shorter, so that the point of attack of the button on the regulating screw which comes in contact with the tail end for the escape of the jack from under the hammer knuckle comes nearer to or further from the turning point of the jack,—that is, the nearer the regulating screw with its button comes to the turning point

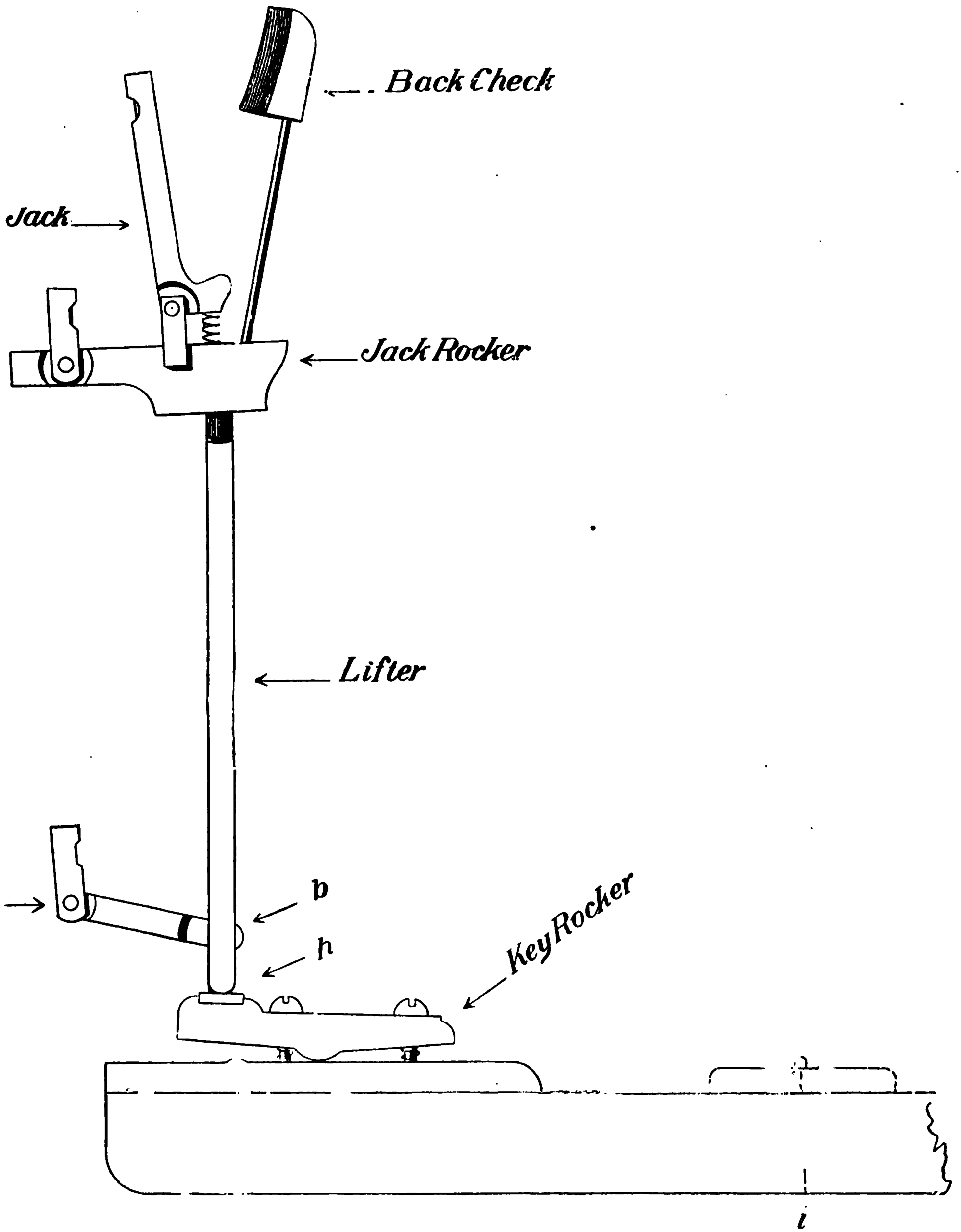


Fig. 16.

of the jack the less is the height to which the back lever on the key rises. However, not this alone but also the point of attack of the lifter on the jack rocker determines the height to which the back lever rises. If, for instance, the point of attack is laid nearer front—that is, further from the turning point of the jack rocker (Fig. 16)—then the height to which the back lever of the key rises will be greater. The reverse is occasioned if the lifter is placed nearer the turning point of the jack rocker.

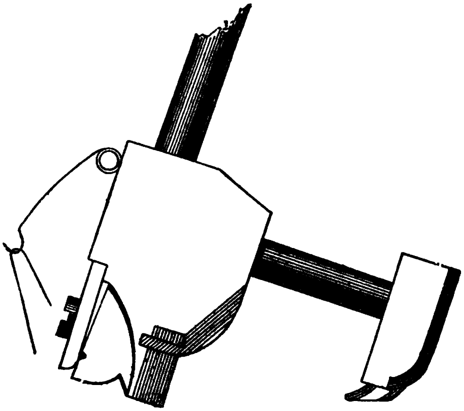


Fig. 18.

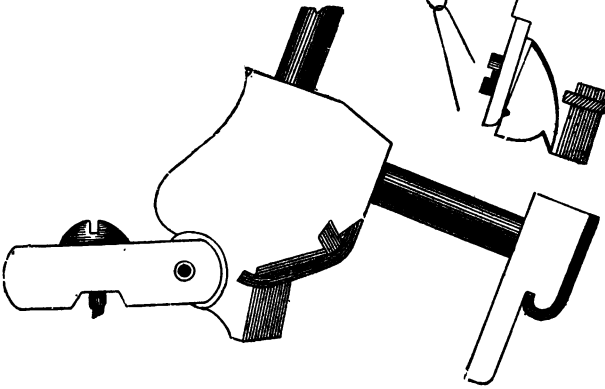


Fig. 17.

The pianoforte maker is mistaken if he thinks that the key may be pressed down with less exertion of force if the point of the lever's attack on the jack rocker is laid nearer front. There is a rule which says: "That which we would save in exertion of force with a lever we must add to the distance." Now, it is a well known fact that if, for example, the point of the lifter's attack on the jack rocker is laid further front, the key may be pressed down with less exertion of force, but that hereby the fore lever sinks deeper because the back lever of the key rises further. We are bound, however, to a certain depth of the fore lever's sinking on account of the touch; and, if now we regulate the greater rising of the back lever with the definite sinking of the fore lever, the point of the key's balance is brought further toward the fore lever. If hereby the fore lever is shortened and the back lever lengthened, then the before mentioned less need of force exertion is again lost.

We see from the foregoing that the division of the key through the point of balance cannot be discretional. Thus, we cannot say that the fore lever stands to the back lever as the number 3 : 2; but the geometric proportion in the length of the two levers to each other is equal to the proportion of depth of the fore lever's sinking to the back lever's rising.

We may have a division of the key according to all rules and regulations, and still have the feeling of a touch which is too deep. Such is found, for example, with the majority of square pianos at the first bass keys, on account of their extraordinary shortness. While we have the feeling of a very deep touch with the very short keys, just the opposite effect is caused by extraordinarily long ones,—as for instance, by the last treble keys of square pianos.

We must, then, consider the length of the keys, and are not amiss if we give the keys of grand and upright pianos a length of 40 c.m., measuring from the fore edge of the key to that place on the same where the lifter and key rocker connect, as in Fig. 16, or (as in Fig. 23) from the fore edge of the key to that point which is vertically opposite to where the key prop meets the jack rocker. The proportion of the back lever's rising to the depth of the fore lever's sinking can influence the effect of the touch just as does the length of the keys. If, for example, the key prop should be placed so near the turning point of the jack rocker that the rising of the key's back lever were only 2 m.m., this would be noticeable in the touch, even with a regulated sinking of the fore lever. A good proportion in the length of the two levers to each other is 3 : 2. This proportion may be obtained with a key in the length of both levers, as follows: the length of the key is 40 c.m., and these 40 c.m. must be divided by 3 + 2 = 5; the result is 8 c.m. The fore lever receives 3 × 8 = 24 c.m. length, and the back lever obtains 2 × 8 c.m. = 16 c.m. length. This proportion of the two levers to each other can, however, only exist if the height to which the back lever rises at its point of attack on the action is 6 m m. The sinking of the fore lever measured at the fore edge of the key should be 9 m.m., thus making the proportion between the rising and the sinking of the key as 3 : 2.

We find in different actions, however, that the rising of tke back lever of the key is rarely 6 m.m.: we have to count with from 5 m.m. to 7 m.m. of rising distance. If the height to which the back lever of the key rises is 5 m.m., the proportion in length between the two levers should be as 9 : 5,—that is, 9 + 5 = 14; the length of the key equals 40 c.m., divided by 14, equals 2·86 c.m. The fore lever receives 9 × 2·86 c.m. (= 25·7 c.m.), and the back lever 5 × 2·86 c.m. (= 14·3 c.m.) If the height of the back lever's rising is 7 m.m., the proportion of both levers in their length must be as 9 : 7.

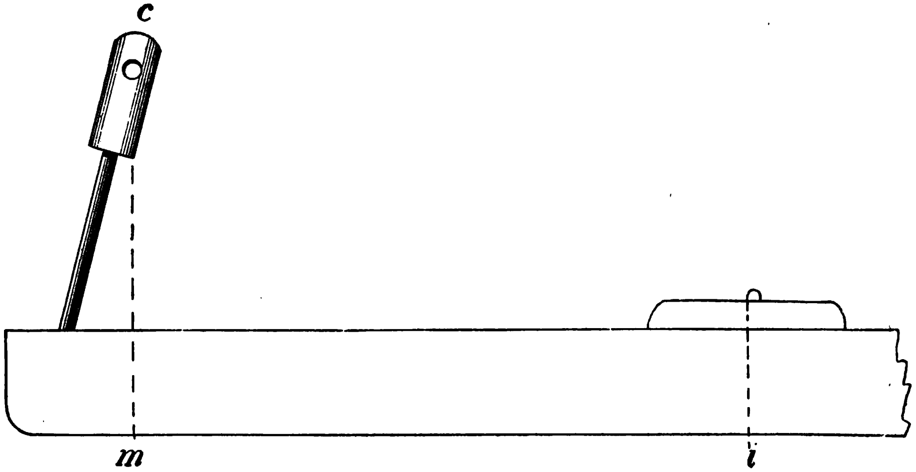


Fig. 19.

The height to which the back lever of the key rises may be easily and exactly determined from the model of the action we intend to use if it is well regulated. As a somewhat deeper touch is preferable for the bass keys, 9 m.m. (the above given depth of sinking) may be left for the last key in the treble, while 10 m.m. sinking may be reckoned for the first key in the bass. With this sinking of the key, the two levers in their length are proportioned if the rising of the back lever is 6 m.m. For example, as 10 : 6, or as 5 : 3,—namely, 5 + 3 = 8 the key's length 40 c.m. divided by 8 = 5 c.m.; the fore lever receives 5 c.m. × 5 = 25 c.m., and the back lever receives 5 c.m. × 3 = 15 c.m. If the rising of the back lever is 5 m.m. instead of 6 m.m., then the proportion in the length of the levers is as 10 : 5, or as 2 : 1; and now the fore lever receives double the length of the back lever &c.

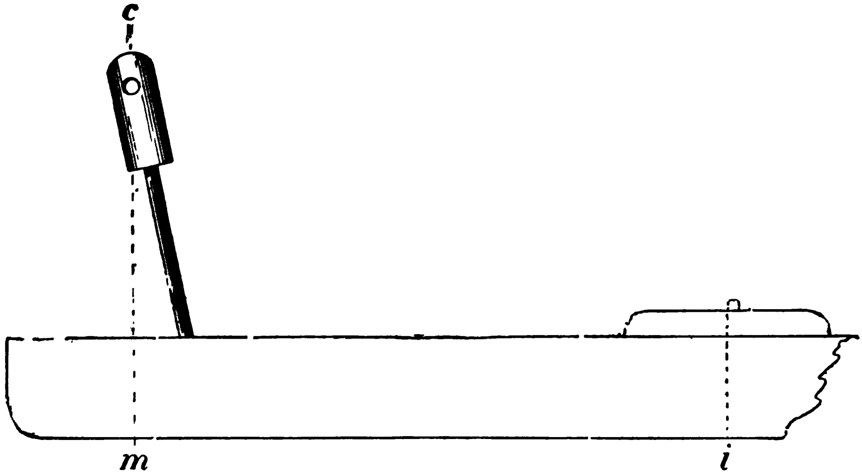


Fig. 20.

Besides the movable abstract as lifter of the action, we have to deal with props as immovable lifters. We come across many erroneous opinions as to the disposition of the props. The following may elucidate.

In Figs. 19 & 20 we find two different positions of props with their wires as connection links to the key. The belief that through a special position of the props to the key the touch becomes heavier or lighter, and that thereby the sinking of the key may be influenced, shall here be refuted. If the position of the prop as in Fig. 20 would make the pressing down of the key lighter and thereby increase the sinking of the same, and if a position of the prop as in Fig. 19 would create the opposite effect, then it would be impossible to unite both positions in one prop and on one key. Fig. 21 proves that this is not alone possible, but that the point at which the wire on which the prop stands is fastened may be laid up to the fore lever of the key without injury to or change in the touch. For example, if we remove the wire of the back lever in Fig. 21, leaving the wire on the fore lever as it is, or if we remove the latter leaving the former unaltered, in both cases the movement of the prop remains the same. Fig. 21 also shows that it is of no import to the touch or the key's movement whether the back lever is in exactly a horizontal position or deviates either upwards or downwards from it. For instance, the wire, when fastened to the fore lever, makes the back lever of the key useless. As far as the fore lever is herein concerned, we must of course strive to obtain a position of the key comfortable for the grasp of the fingers.

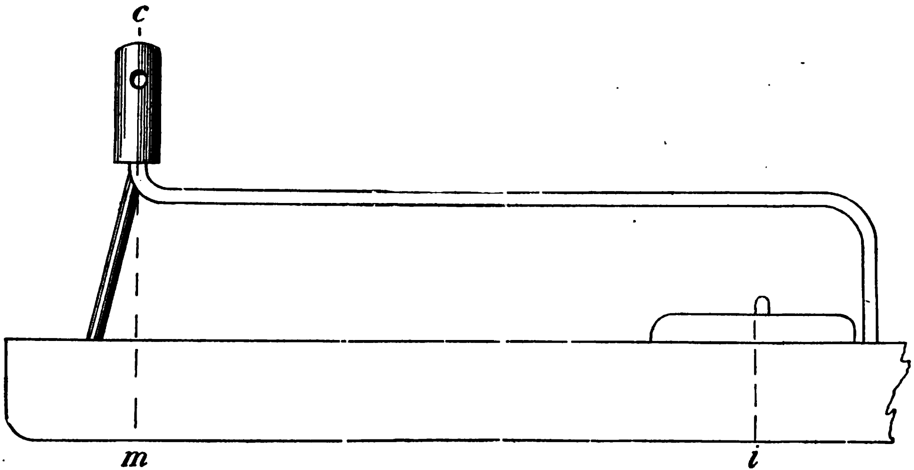


Fig. 21.

We see from the various positions of the props that it is of no significance to the touch whether the lifter stands vertically or deviates backwards or forwards from this position. Fig. 22 shall instruct us whether or not the same is true of the abstract as lifter. In Fig. 22 we find in the line *c-g* the position of the abstract when at rest, while the line *d-h* represents its position while pressing the key. Point *a* is the turning point of the jack rocker, and point *c* a turning point and point of attack of the abstract on the jack rocker. The segment *c-b* shows the movement of the jack rocker at the turning point of the abstract. The distance from *d* to *b* shows in perpendicular line the greatness of the rising height. We recognise from the position of the line *a-c* and from the move-

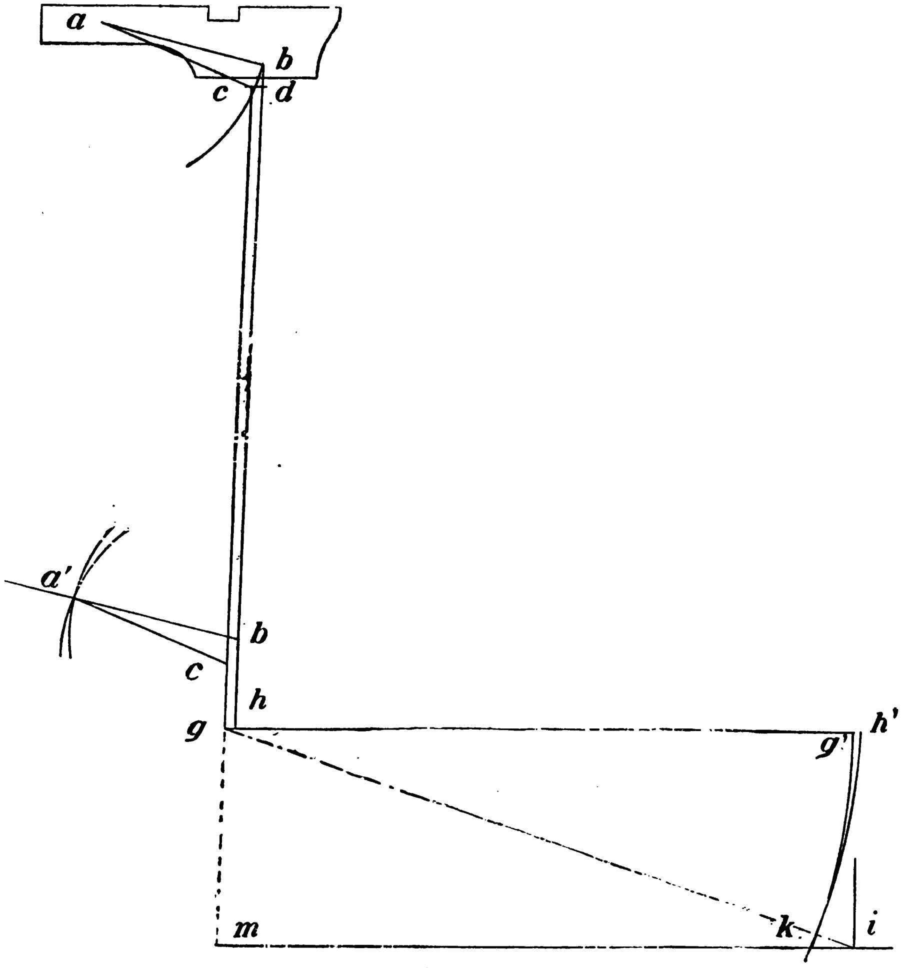


Fig. 22.

ment of the jack rocker *c-b* that it can only be beneficial for the position of the abstract $c\ c^1\ g$ for lifting the jack rocker, if the abstract tends at its lower end *g* backward from the perpendicular line and not (as it is often made to do) forward. The movement of the swing from c^1 to b^1 in Fig. 22 should agree exactly with the movement of the jack rocker from *c* to *b*, so that at the lifting of the action the line b^1-*b* of the abstract runs parallel to the line c^1-*c*, and not have the movement of the swing arranged according to the movement of the key at the touching point with the abstract. In order to give the swing flange rail—or, better said, the turning point a^1 of the swing in its flange—a position according to the movement of the jack rocker, we take the height of the jack rocker's rising *c-b* (Fig. 22), and draw a line from point *b* parallel to the line *c-g*. We give this line, extending from *b* to b^1, exactly the length of line *c* to c^1. Next we draw an arc from point c^1 toward a^1, taking a radius equal to the distance between the two turning points a^1 and c^1 in the swing; and a second arc (with the same radius) from b^1 towards a^1. At the point of the arcs' intersection is found point a^1 in the swing. Accordingly the movement *c-b* from turning *a* of the jack rocker corresponds with the movement c^1-b^1 from the turning point a^1 of the swing.

The movement of the key must be determined by the movement of the abstract at its lower end *g-h* (Fig. 22), and we must therefore place the balance point of the key at its balance rail accordingly. For this purpose let us measure with compasses the length of the back lever of the key from its point of balance to the abstract, and with this measurement as radius draw an arc with point *g* of the abstract as centre. A second arc must be drawn with point *h* as centre; both arcs must tend downwards. Where the arcs intersect is a turning point (*k*), for the key at which it has a like movement as the abstract on the segment *g-h*.

Hereby, however, we find the fault that the back lever is shortened; we therefore draw a perpendicular line from g^1 downward, and a parallel line *k-m* to the line *g*-g^1. Taking the length of the diagonal line *g-i* for radius, and drawing two arcs from *g* and *h* respectively, we find at their point of intersection the turning point of the key on its balance rail.

Correctly executed, this point must be in the line *g*-*i*. Notice that the line b^1-*h* on the abstract must have the same length as the line c^1-*g*, and not as we see the line b^1-*h* in Fig. 22.

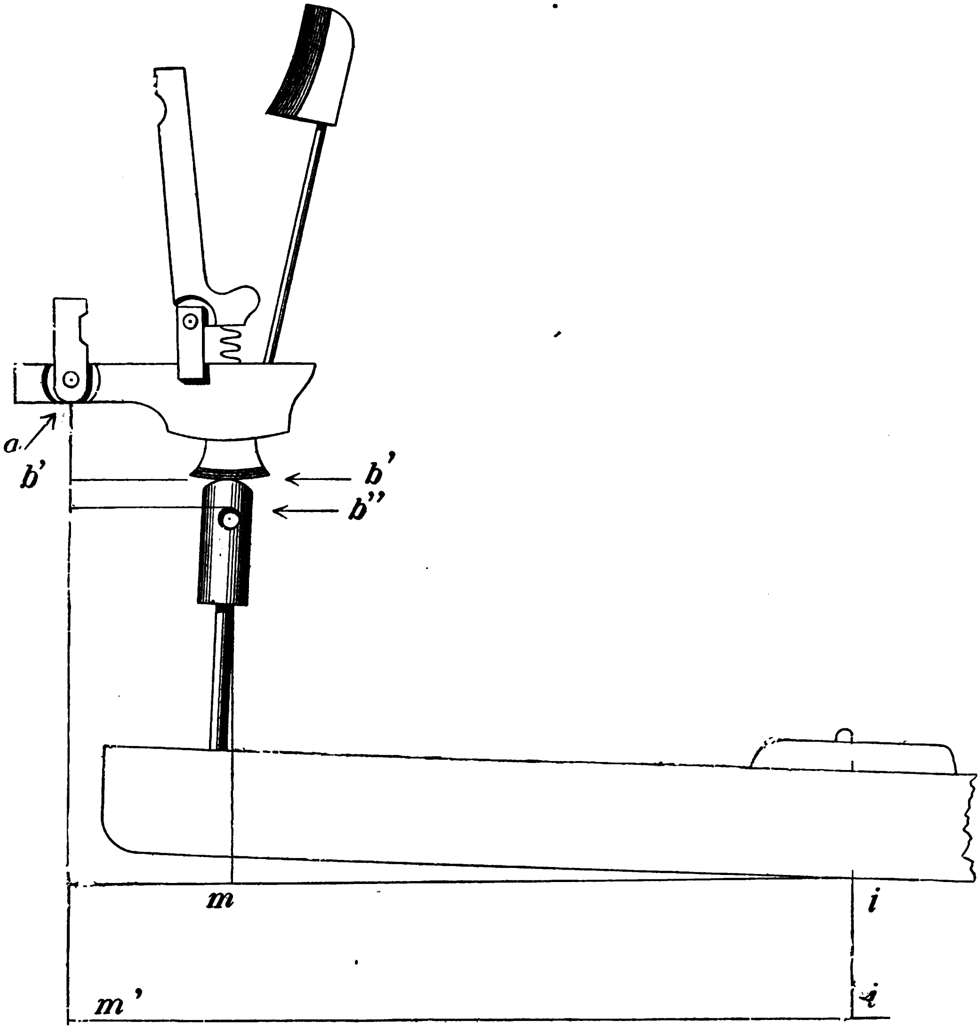


Fig. 23.

At any rate, one must be willing to take into consideration such faults and defects of the drawings as have been formed in copying.

In Fig. 16 we find the key rocker fastened on the key under the abstract. Lately, however, the brass prop or capstan screw (which is screwed into the key and stands under the abstract instead of the key rocker) has been extensively used. The capstan screw is in every way preferable to the key rocker. We find dowel props applied not only under the abstract but (as in Fig. 23) in place of the abstract itself.

Abstracts have movable parts, whereas props must be considered immovable lifters; and therefore the curve which a prop describes under the point of attack on the action may be very large. In order to calculate rightly for this curve or segment, we have often to put a considerable footing under the jack rocker (Fig. 23). With this arrangement the height of the key's rising must first be determined with a model perfectly regulated. In Fig. 23 the height of the key's rising is shown by the lines b^2 and b^1. We determine the balance point of the key according to the foregoing explanation from the height to which the back lever of the key rises, and from the sinking of the fore lever. The balance point of the key on its balance rail may be determined on the horizontal line m-i, through a perpendicular line drawn from the point of attack b^1-m. It is our aim to have the movement, at the point where the jack rocker and prop meet at the lifting of the action, occur without friction of the two parts. We describe the course of the jack rocker from b^2 to b^1 with compasses from turning point a, and then try (with the compasses) from the balance point i of the key whether the two segments, drawn from the points a and i, cover the course of the rising height from b^2 to b^1. If they do not, it may be determined by the above described way whether the foot under the jack rocker has to be lengthened or shortened. In this wise friction of action parts may well be avoided.

Let us treat as carefully of grand actions; sufficient instruction will then have been given to study alone. Fig. 24 is a representation of a grand piano action as it is generally found in the grand pianos of to-day. Before we dissect this action. we will become acquainted with its various turning points. We distinguish local turning points,—that is, those

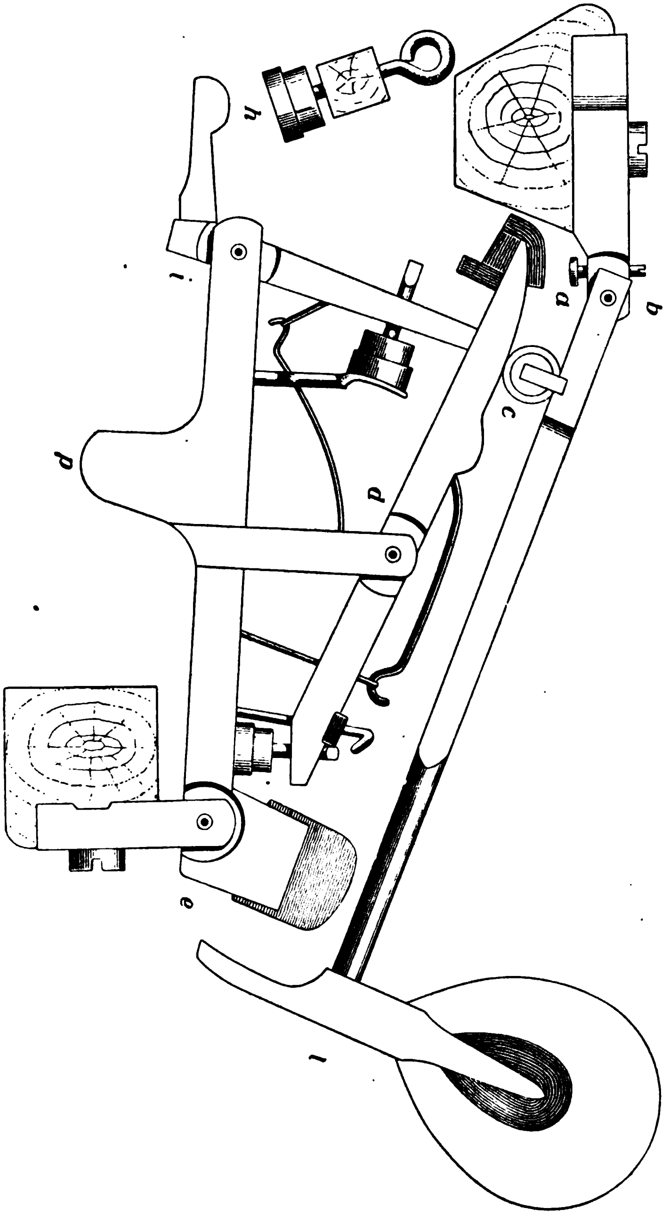
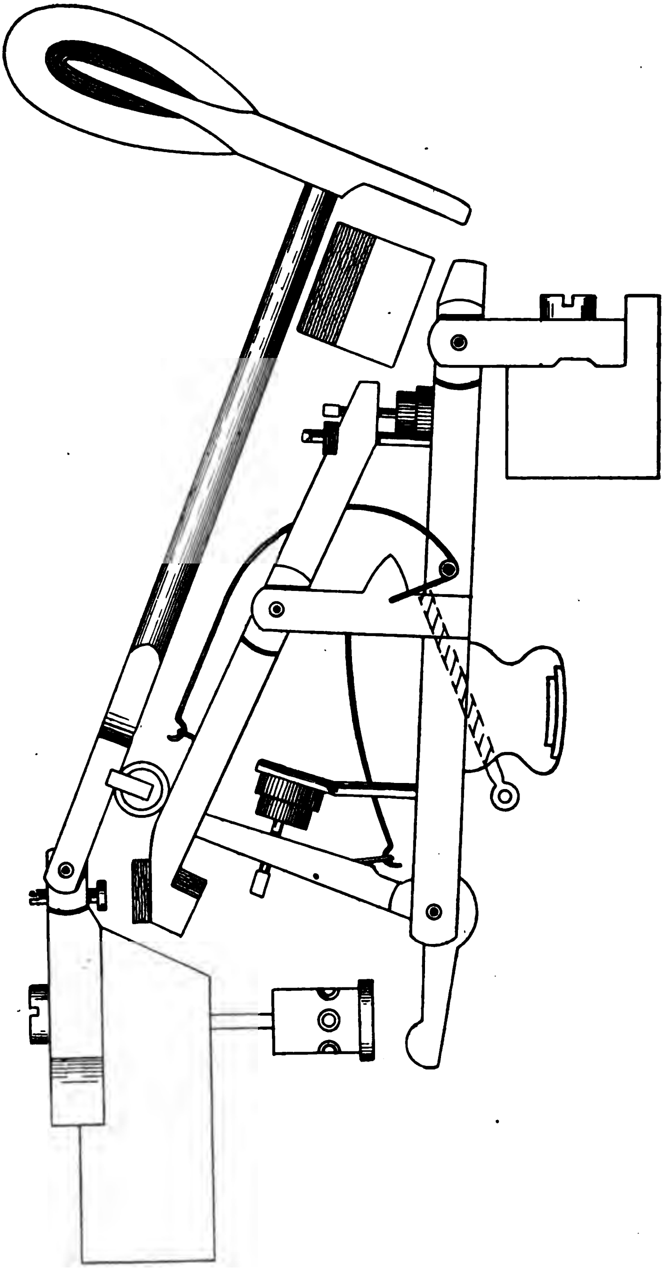


Fig. 24.



Improved Erard—Herz Grand Action from F. Langer & Co.

which do not leave their places during the movement of action parts from those which do change their locality during such movement. The upright action has but one changeable turning point (excepting the abstract), and that is on the jack rocker, whereas the grand action has another changeable turning point *d*, beside the turning point *i* on the jack, on the escapement lever in connection with the escapement lifter. We find a local turning point *b* on the hammer shank and a second one *e* on the jack rocker. From this explanation we have learnt the names of the main parts of the action.

In Fig. 25 we find the grand piano action laid out in lines and points. By this means we can easily follow the course of the action parts during their respective movements. The line *b*-*l* in Fig. 25 represents the hammer shank's position; *b* is the turning point of the hammer shank, and *b*-*l* its length, while point *l* indicates the middle of the hammer head. The segment l-l^1 drawn from the point *b* gives us the rising distance of the hammer shank. Point *c* belongs to the point of attack which the escapement lever has with the hammer shank knuckle. We can investigate how great the friction of these two parts is during their movement. For this purpose we place the compasses on point *b*, and taking *b*-*c* for a radius follow the course of the hammer shank knuckle from the point *c* to its height of rising, c^1. In order to follow at point *c* the movement of the escapement lever, which is connected with the jack rocker by the escapement lifter and is therefore led by the course of the jack rocker from turning point *e*, we draw an arc from c^1 to c^2, taking *e* for centre and the distance from *e* to c^1 as radius. The distance between the two segments from c^1 to c^2 shows us the extent of the friction of the two parts with each other. We find from the height of the hammer shank's rising at the point *c* the height of rising of the escapement lever from c^2 to c^1—or, better said, the height of the jack's rising—for the escapement lever is hindered by the regulating screw *a* from making the full course to c^1. Knowing the jack's rising height, we find the height of the key's rising from that of the jack rocker at its point *p*.

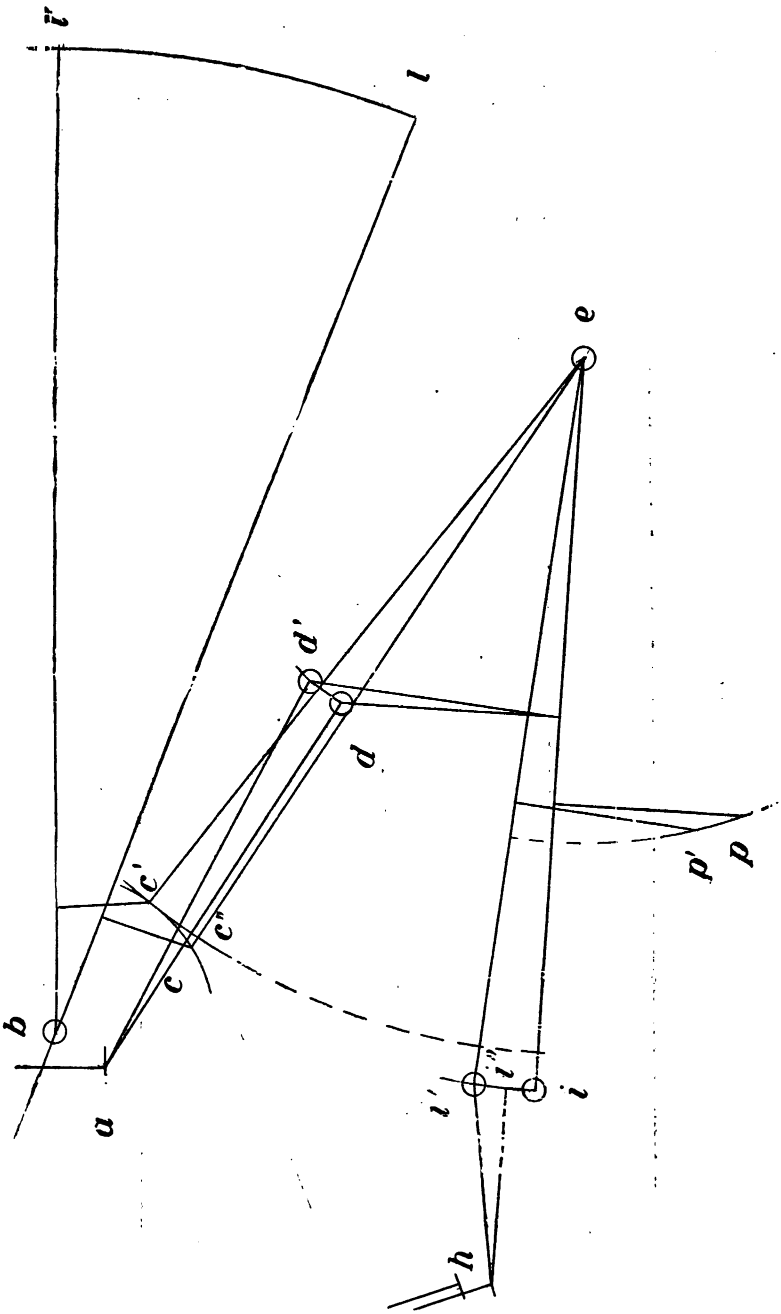


Fig. 25.

The movement of the key must be regulated at its balance point *k* (Fig. 26) after the movement of the segment p-p^1, drawn from the jack rocker's turning point *e*. In order to bring the

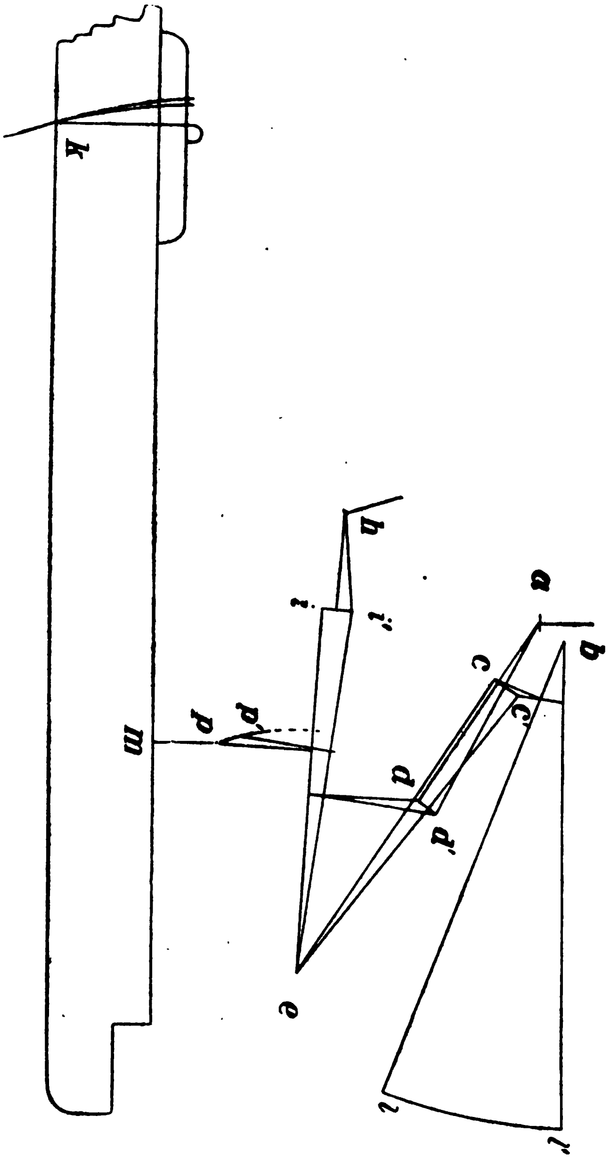


Fig. 26.

movement of the key in accordance with the segment p-p^1, after the balance point of the key has been determined by the proportion of its two levers, we can draw an arc from p with the radius p-k through the point k. With the same radius draw an arc from p^1, and if the two segments do not meet at k, we must give the balance point of the key another position and change the foot on the jack, &c. The exact regulation of the separate action parts does not belong to the technical sphere, but rather to that of practical execution, of which we will deal in a subsequent chapter on repairing pianos.

In Fig. 27 we find a grand action with compensating lever on the hammer shank for which the writer was granted the United States patent (June 4th, 1889). This action does not alone excel in a light, elegant touch, but especially in a strong, elastic stroke of the hammer on the strings. The compensating lever allows light, elastic springs for the exceedingly heavy bass hammers; instead of the thick, stiff, repeating springs under the escapement lever. Every pianoforte maker will appreciate this property in a grand piano action. Having thus far treated of the action, let us turn to the division of the grand piano keys.

At an early date, when grand piano strings ran almost parallel one beside the other, and when the action was fastened only at its two extremities by brackets, it caused no great difficulty to lay out the keys according to the division of the strings. With the introduction of the overstrung system, however, many difficulties arose for the laying out of the keys; and the task became the more difficult as two more brackets were applied between the two end brackets. With such an arrangement it is impossible always to put the balance point of a key where it should naturally be; however, with some knowledge of the state of affairs, the fault can be considerably weakened.

In Fig. 28 we find a key bearing a piece of lead on its back lever. The balance pin is situated aside the key; and if, we imagine the customary balance punch under the key on the balance pin, every pianoforte maker knows that the movement

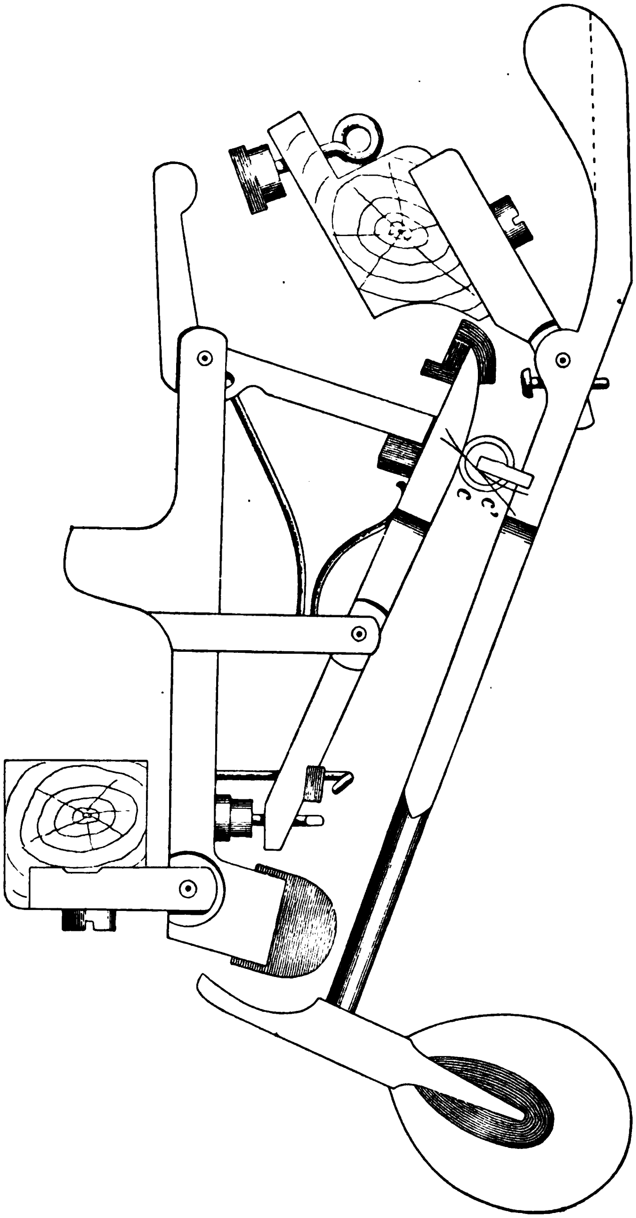


Fig. 27.

of the key cannot be executed correctly, and he can state easily just where the pin should stand. Not so well does every pianoforte maker know how to give the balance pins of grand piano keys their proper—or, let us say, best possible—place.

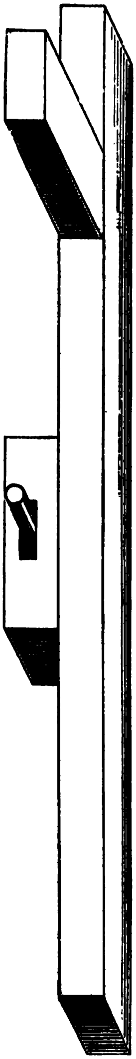


Fig. 28.

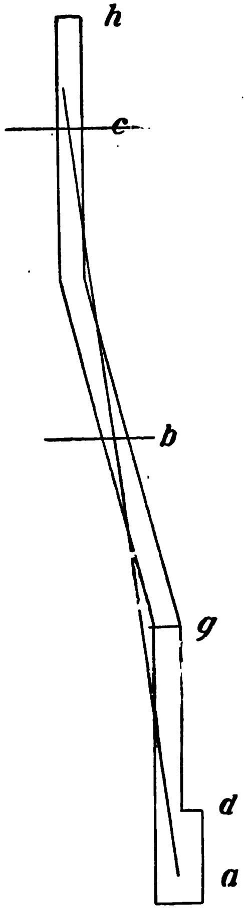


Fig. 29.

In Fig. 29 we find a key with a considerable curvature. Point *a* indicates the spot where the front pin is placed. Point *b* is for the balance pin, and point *c* for the brass prop, &c.

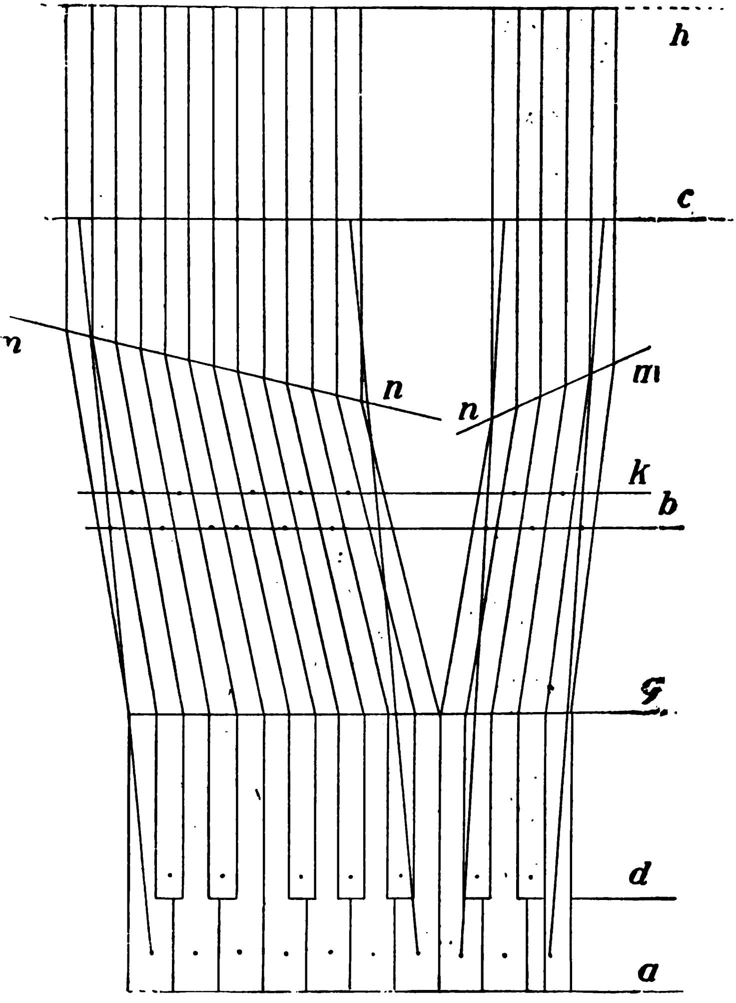


Fig. 30.

Drawing a straight line from point *a* to *c*, point *b* or the balance pin must be in the line thus drawn. In this way an inclination of the key toward the side, as is the case for example with the key in Fig. 28, is prevented. We see that no better place could be found for the balance pin with the key, Fig. 29.

In dividing the key in Fig. 30, the line for the front side of the key is drawn first, then the line *d* for the front ivories, furthermore the line *g* for the termination of the finger-board, the line *b* for the balance pins in the balance rail, and likewise the line *k* for the balance pins of the sharps; the line *c* for the brass props, &c., and the line *h* for the termination for the key lengths.

We give the front line a length equal to the width of all keys. With 88 keys, this length equals 121·5 c.m. With this number of keys, the front line has 52 equal parts, which we draw at right angles to the front line and extending to the line *d*. We must not fail to draw the lines separating the keys *b* from *c* and *e* from *f* up to the line *g*. Through this we have a row of special divisions on the line *g* where greater and smaller divisions interchange. Into the smaller divisions we must place the keys for the notes *c c♯ d d♯* and *e*; according to this, we must divide the divisions on line *g* for these keys into five equal parts. The larger divisions, intended each to hold the keys for the notes *f f♯ g g♯ a a♯* and *b*, we must divide each into seven equal parts. From all these points of division on line *g*, we now draw lines at right angles to line *d*, and the laying out of the finger-board is herewith completed.

We must make a division of the keys on line *c*, exactly after the division of the strings as given in the scale, on the line for the striking points of the hammers. The two end keys of each division (according to foregoing explanation, Fig. 29) receive their balance pins in the line *b*; or, if the end key be a sharp key, in the line *k*. We can draw the outer line of the first key in Fig. 30 from *h*, beyond *c*, perpendicular to the front line of the keys, and then determine where the outer line of the key is to meet the line *b* from the balance pin, and draw the line *g-b* beyond *b*; the point *m* lies where the lines *h-c* and *g-b* meet. Likewise point *n* of the key on the other side of the same division must be found; and if, as seen in

Fig. 30, we join points *m* and *n* by a line, then after having made the divisions for the keys on the line *c* we can continue the lines *h-c* to the line *m-n* and then draw the connecting lines from the line *g* to the line *m-n*. In this wise the position of each key is laid out in the drawing; and, if we now indicate the points for the balance pins on the lines *b* and *k* in the middle of each key's breadth, we have done the best possible for the balance of the key. We acknowledge that piano making pursued as an art requires extensive technical study.

Royal Prussian State Medal
1896

Paris 1900.

Berlin 1896

Chapter XIII.

Piano scale drawing.

In the foregoing chapters of this book we became thoroughly acquainted with the acoustic properties of a piano and will now immediately begin with the sketching of a piano. For the learner it will be of special interest if we choose a grand piano for this purpose and that a small model of 175 c.m. length. Firstly I would like to say a few words about the drawing utensils.

The drawing-paper must be spread upon a practical drawing-board. It is not advisable to spread the paper intended for the drawing upon a simple board. We must remember that after finishing the sketch, all the points representing the places for tuning pins, bridge pins, plate pins, screws, likewise for the various lines for the sounding-board bridge, iron plate etc., must be transferred from the drawing upon a wooden pattern. Every one is acquainted with the general method of gluing paper to a drawing board: the paper is moistened and obtains a special tension in drying; it is then glued with its four rims to the board. In removing it one is compelled to cut it at these glued rims, thus causing a change in the shape of the paper. Large sheets of paper are very inconvenient to handle. These reasons induce us to seek a better method. The drawing board best suited for our purpose consists of a frame which is 156 c.m. broad (the drawing paper being obtainable 152 c.m. wide) and as long as the purpose demands. Each of the four rims of this frame must be 5 c.m. wide and like the drawing board, 2 c.m. thick. The drawing board has four furrows in its four outer edges which fit it into furrows running along the inner edges of the frame, thus making it possible to remove the board from under the drawing and replacing it. In this wise one is enabled to insert the veneer upon which the dots and lines are to be transferred by means of pin points, between paper and board. The points are easily transferred from the veneer pattern upon the models to be made. The drawing is fastened to remain in the frame, thus protected and always ready for use.

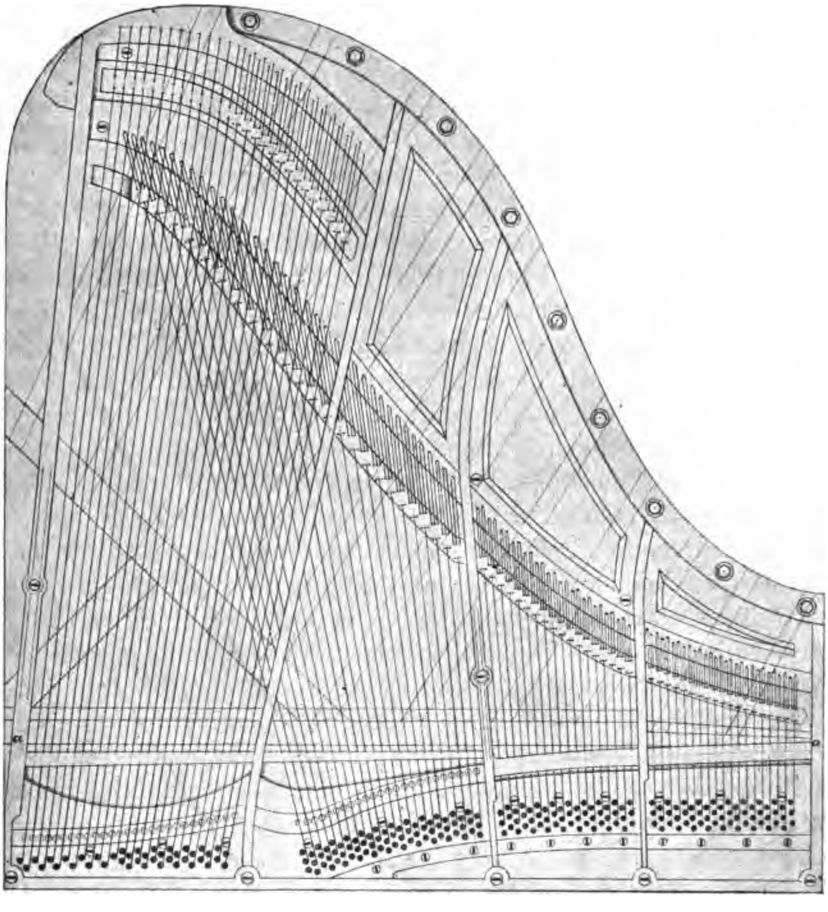


Fig. 31.

The first line to be drawn is the line *a*—*a* (Fig. 31). This line denotes the place where the strings are struck by the hammers; therefore we call it the hammer line. From this line we calculate the length of the strings and it is the standard for many other things, so for instance in sketching the action.

Upon the hammer line we must first place the divisions for the strings and the respective spaces between them. Where three strings are used to produce one tone, we draw only the middle string, this line sufficing for the three strings; where two strings are used for one tone we draw a line lying exactly in the middle of the space between the two strings. The distances of these average lines from one another on the hammer line must be 1·3 c.m., because the damper wires between the strings, stand very near the hammer line; there however, where the strings run in a direction very oblique to the hammer line, the distance from one average line to the next must be increased enough to give ample space for the strings to be placed between the tuning pins. For the last three treble strings the average line is to be drawn at right angles to the hammer line and the following lines may be drawn in a gradually increasing obliquity to the hammer line. In order to obtain a good proportion a line must also be drawn to represent the position of the first uncovered strings; the average line in the high treble must then be lengthened so much that one may draw a line parallel to the hammer line at the lower extremities of these two lines. Then the space between the two lines is to be divided into as many equal divisions as average lines are needed for the covered strings. Be sure to remember the iron bars while making these divisions. The dots denoting the divisions on the parallel line must be so connected by means of lines with those on the hammer line that these connecting lines reach the tuning pins. The lines must be so lightly drawn that superfluous parts may be easily erased: they may be darkened afterwards from tuning pin to plate pin. In Chapter 8 we find sufficient instructions for the dimensions of strings.

The length of the strings must first be marked on a strip of wood, starting at a certain point, whereby we obtain geometrically increasing divisions; a certain proportion must be observed there also where the use of covered strings ends and the use of uncovered strings begins, which latter are of necessity to be shortened. Before we transfer the string lengths from the wooden strip upon the average line in the drawing, we must question ourselves at what point on the string's length the hammer is to operate. Views on this point differ vastly, and the theoretic assertions of Helmholtz are by no means valid. We have discussed this subject in previous chapters of this book. In order to obtain a clear understanding for the contents of this chapter it is necessary to have a thorough knowledge of the contents of all foregoing chapters. It remains a fact that every piano of different make has its own individualities and must be individually treated, so also as to the striking point of the hammer. So for instance, pianos manufactured at earlier periods, with their thin strings and slight tension, with thin sounding boards and weak bars, never could bear a striking point in $\frac{1}{8}$ or, like many pianos of to-day, in $\frac{1}{7}$ of the string's length. Baised on the results of my practical trials, we will take the striking point in our sketch at $\frac{1}{10}$ the string's length for the treble strings between the first iron bars, the following section between the iron bars at $\frac{1}{9}$ and the two remaining sections at $\frac{1}{8}$ the string's length. Hereby the eighth part of the string's length is marked on the respective average line measuring from the hammer line toward the wrest plank. The point thus marked represents the place for the agraffe. Then measure $\frac{7}{8}$ on the opposite side of the same line again measuring from the hammer line. The point marked here represents the place for the front bridge pin. The same mode of measurement must be observed where the striking point of the hammers on the strings is calculated to be at $\frac{1}{9}$ and at $\frac{1}{10}$ their lengths. Before the hammers are glued to their shanks however, the striking point for the strings of the last treble tones must be determined by means of the ear. Hereby one will find that the striking point for the hammer on the strings of five lined *c* may be at $\frac{1}{14}$ the string's length, and for four lined *e* in $\frac{1}{12}$ the string's length. In our sketch however, we may well use the measurement $\frac{1}{10}$ as, with these short strings, a marked difference will hardly be obtained in the hammer line. I only wish to show that the striking point cannot be the same on all strings. Here with the foundation for designing a stringing scale is laid and the farther progression of the work is easily understood from Figure 31. In Fig. 32 we find a separate sketch with instructions for the wooden model which serves in forming the iron frame.

In order to facilitate the designing of the wooden model for the iron frame, fasten a transparent paper over the sketch of the stringing scale. This paper is also obtainable in the desired length and width. The transparency of the paper makes it unnecessary for us to copy the iron frame from the sketch of the scale: we can immediately begin the calculations necessary to draw the lines correctly for the sketch after which the wooden model is to be made. In Chapter X "Cast Iron Frames of Pianos" enough has been said about the shrinkage of cast iron and the calculations necessary to make the model. Never the less, in sketching the grand piano I would like to refer again to the subject.

The line *a-b* in Figure 32, representing the fore-edge of the iron frame at the wrest plank, is to be considered as stationary so that the shrinking in casting the frame is calculated to extend from the opposite side toward the fore-edge of the wrest plank; the outer frame line *a-c* in the treble is also to be considered stationary and the shrinkage here extends from the bass border toward the treble. The quotient for this double shrinkage is noted with 1·02. Firstly we must care that the spaces between the iron bars where the stringing scale is placed are made as much larger in the wooden model as the shrinkage demands; hereby the iron bars are moved farther toward the bass. How far each bar is to be removed we will learn from the following.

Every division in the form of the iron frame is bordered by a line in the drawing. If we wish to place a new line at a certain distance from one of these lines in the drawing, we need only know the distance between the ends of the old line and the extremities of the new one, so that we may draw the latter by connecting the points representing these extremities. It also suffices, in drawing the sketch for the wooden model, if we place certain points by means of a calculation with the shrinkage of cast iron. For example, let us place in the sketch the centers for the scerew holes which are bored in the front iron bar on the wrest plank. The screw hole in the treble corner *a* (Fig. 32) is stationary. The center of the next following screw hole lies 30 c.m. from the line *a*—*c*; this distance must be multiplied by the quotient 1·02: the result is

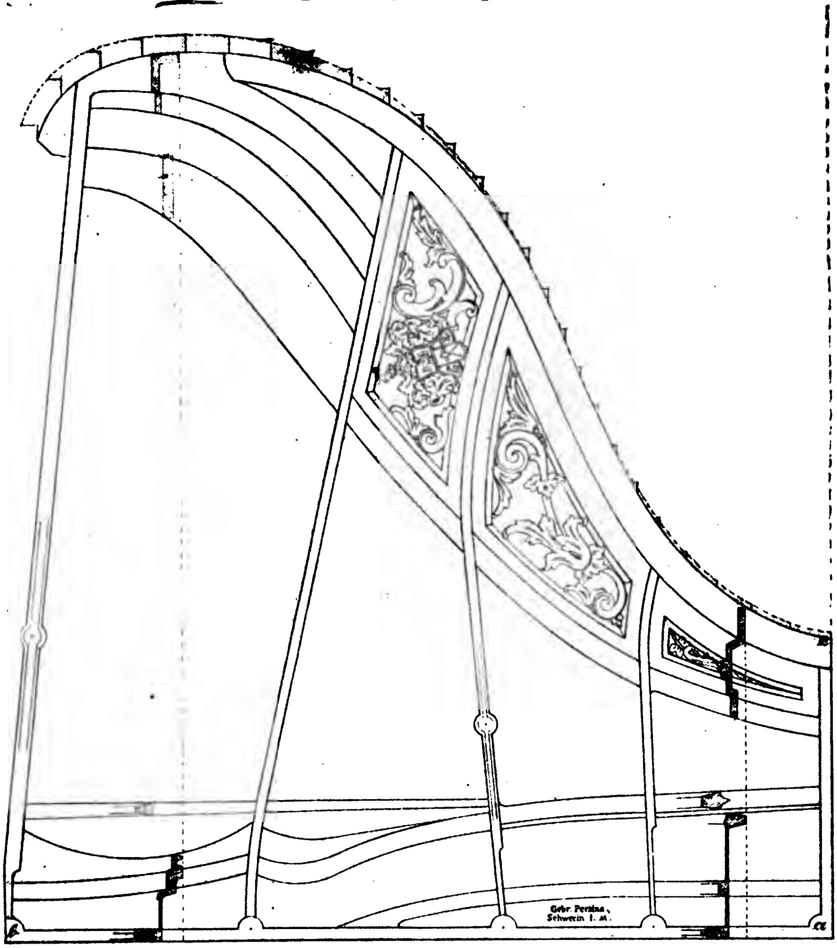


Fig. 32.

30·6 c.m. The difference between 30·6 c.m. and 30 c.m. is 6 m.m. so that we must remove the point 6 m.m. toward the bass on the iron bar. In placing the centers of the other screw holes in this iron bar, the same mode of calculation must be employed. In placing the points for the screw holes in this iron bar we need not, as we must hereafter, consider the shrinkage from the line *a—b*, because here the difference amounts to nothing. Now let us place the center of the screw hole in the middle of the third iron bar running in the direction of the strings. Measuring from the line *a—b* the center lies 36·5 c.m. from the same; this distance multiplied by 1·02 equals 37·2 c.m. The difference between the two sums is 7 m.m. We must mark these seven millimeters on a line drawn through the old point and at a right angle with the line *a—b*; from the mark we now draw another line at right angles to the line *a—c*. Measuring the distance from the mark to the line *a—c* which we find to be 57·2 c.m., we multiply this sum by 1·02 = 58·3 c.m. The difference between 58·3 c.m. and 57·2 c.m. = 11 m.m. We must now remove the mark 11 m.m. toward the bass. This point is now 7 m.m. farther from the lines *a—b* and 11 m.m. farther from the line *a—c* than the first point with which we began to measure and is therefore the average point. In placing a straight line we must find its extremities by the above method and then combine these points by a line. A curved line is treated likewise with the exception that several points within the curve must be measured and carefully placed by means of calculation before the line can be drawn correctly. For farther explanation see Fig. 32 where the measurements of the rim of the iron frame are carried out by the above method of reckoning. The figure shows the measurements of the shrinkage of the lines *a—b* and *a—c* fully carried out. The placing of points for curved lines is so plainly shown in Fig. 32 that a misunderstanding seems improbable. In placing a curved line in the drawing for the model, do not become confused if the old line and the new one ofter coincide, and if the distance between them often widens and contracts. Upon consideration one will see that this process is correct because in the skrinking of cast iron all the measurements of the wooden model will return to the original positions, whereby the form of the iron frame will correspond with the sketch in the drawing of the stringing scall. It is to be seen from these strange changes in the form of the model and iron frame that, without carrying out all the points as taught above, the iron frame will not appear as it is sketched in the drawing of the stringing scale. The execution by means of the above method has been practically employed by me dozens of times and I can highly recommend the same.

The basis upon which the wooden model is put together is a straight firm board, from the surface of which the cross cut of the raised parts in the various divisions of the iron frame, as they are represented in the drawing, are measured. For this purpose there is a dotted line under the cross cuts which represents the surface of the board: see Fig. 32. Various things might yet be discussed in making the models, which however may well be left to the sagacity of the individual. We will now give our attention to the case of the grand and a proper fitting up of the mechanism in this case.

Fig. 33 represents the front part of a grand in its cross cut.* The space from the uncovered strings up to the bottom board frame is 21·5 c.m. deep. The hammer line determines the position of the cross beam, under which the bottom board frame with its back frame piece is fastened and against which the beams running in the direction of the length of the piano also lean. Drawing a perpendicular line for this purpose from the point at which the hammer strikes the strings (see Fig. 33) to the bottom board frame, the distance of the cross beam from this line is 10·5 c.m.; the higth of the beam is 10 c.m. and the thickness 5 c.m. Upon this beam another one is glued of 11·5 c.m. width, 5 c.m. thickness which diminishes into a thickness of 3·5 c.m. toward the back rim. Through the 11·5 c.m. width of this beam a projection of 6·5 c.m. over the other beam is obtained under which the damper levers find

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* The action is a representation of the patented model of the firm Schwander, Paris. The productions of this house are world renowned and through their manifold improvements favourites of many piano makers.

The actions from the factory of H. F. Flemming in Leutsch by Leipzig Germany are highly worthy of recommendation. These actions are used by prominent piano manufacturers.

The firm F. Langer & Co., Berlin has also a considerable number of purchasers in Europe which is proof for the excellence of the actions which are of superior workmanship.

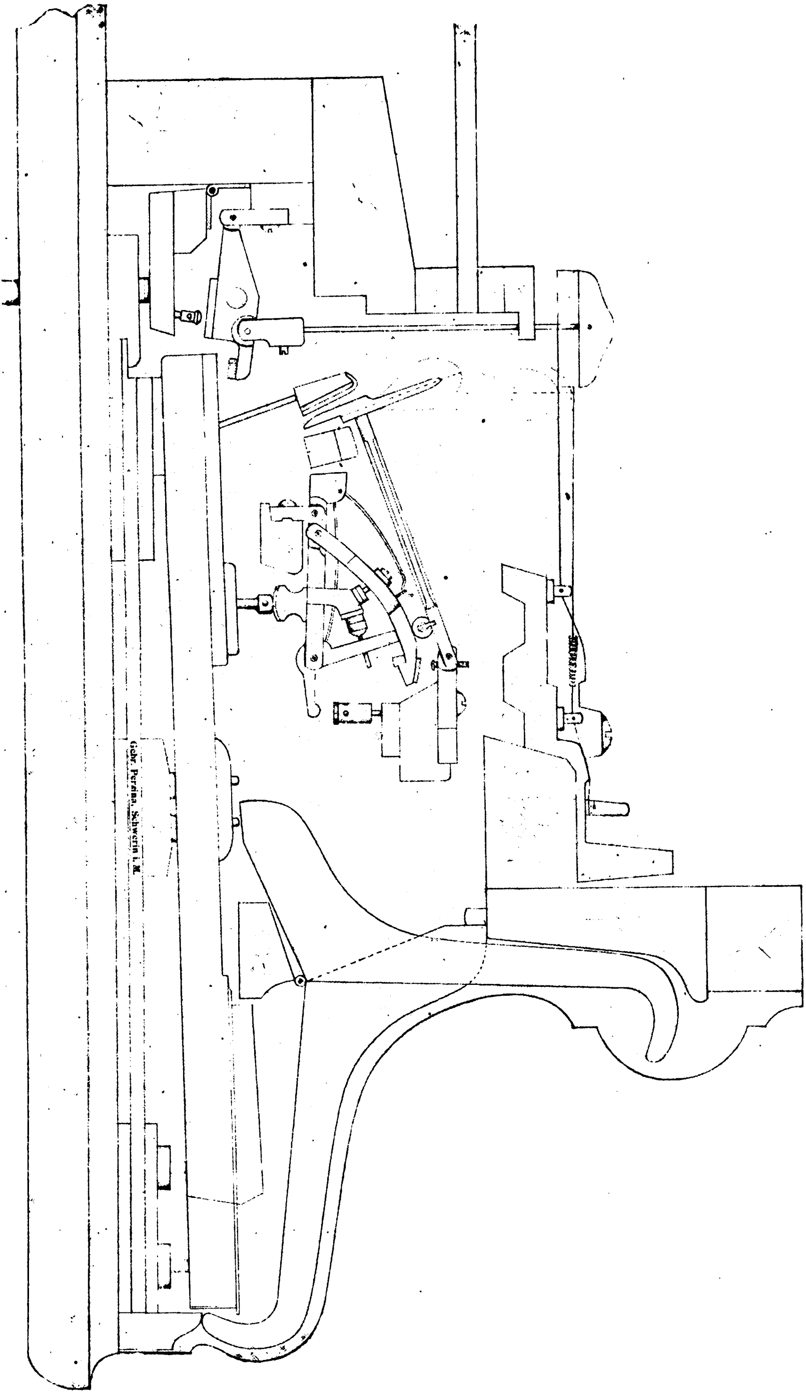

Fig. 33.

their place. On the projection a strip of wood 2 c.m. wide and 2 c.m. high is glued as a support for the sounding-board; the edge of this strip must run exactly over the fore-edge of the projecting beam. (Fig. 33). As the sounding-board is 1 c.m. thick here, a highth of 4 c.m. remains for the sounding board bridge which highth increases 2 c.m. at the bass bridge. The space between bottom board frame and under-edge of the wrest plank is 18 c.m. for the insertion of the action. A professional piano maker will need no farther instructions. We will now proceed to sketch the action: —

Firstly we place the hammer at the striking point on the strings. We draw a dotted line through the middle of the length of the hammer head. The hammer must stand so that this line is at right angles with the strings when the hammer strikes the latter. The hammer head is 5 c.m. long from the outer felt edge to the middle of the hole intended to receive the hammer shank. The hammers under the covered strings however, are 6 c.m. long because the covered strings lie 1 c.m. above the uncovered strings at the hammer line. The hammer shank stands at right angles to the hammer head and runs in a parallel line with the surface of the uncovered strings when the hammer stands under the strings. The length of the hammer shank is 13 c.m. from its turning point to the middle of the hammer head. The placing of the other members of the action depends upon the make of the action used in the grand.

In order to represent the iron frame in the cross cut drawing we must transfer the front edge of the same from the drawing of the stringing scale. (Fig. 31) This is most conveniently done by measuring from the point of the hammer line. The highth of the position of the iron frame and its agraffes etc., in the piano depends upon the highth of the position of the strings, after this is transferred to the cross cut drawing the wrest plank is also taken up in the same.

The fore-edge of the iron frame with the moulding at the wrest plank which receives the fall board when the piano is opened, must necessarily be drawn in the sketch in order to place the fall board, the position of which determines the length of the keys. At the turning point of the fall board, care must be taken that in opening and closing it the back part does not touch any part of the action and that when closed, the back part stands as high as the under edge of the wrest plank.

After the length of the keys has been determined we must see from the base piece of the escapement lever rocker, at which part of the key the brass props or capstan screws shall stand. Knowing the length of the keys measuring from the front edge to the prop, we must determine the balance of the former. For instance, the props in our sketch stand 34·5 c.m. from the fore-edge of the keys, the action rises 5 m.m. and according to the light touch of modern pianos one may count on nearly 10 m.m. fall at the fore-edge of the keys. From the relation of the lifting of the action parts and the fall of the keys, the relation of the length of the back lever and the fore-lever is gained. In regulating the action we would obtain a fall of a little more than 10 m.m. so instead of using the proportion 5 : 10 or 1 : 2 it is better for us to use 5 : 9·5. We add 5 + 9·5 = 14·5 and divide this sum in the length of the key measured up to the prop. In the sketch this length is marked with 34·5 c.m. so the result of our calculation is 2·38 c.m. The back lever of the key now obtains 5 × 2·38 c.m. = 11·9 c.m., and the fore lever 9·5 × 2·38 c.m. = 22·6 c.m. It is well nigh impossible correctly to fit an action in the grand without first having made an exact drawing of the same. I would like to give a few hints which if observed will help the finisher to fit all actions exactly alike on their key frames. There is the turning point of the escapement lever rocker, also the turning point of the hammer shank; both are stationary because they do not change their stand when the action operates. The other turning points in the action change their places during this process and are therefore movable. The two stationary turning points are capable of giving us a certain aid in fitting the action. In fitting the action upon the key frame we take a square to our aid upon the one edge of which we fasten two wires the extremities of which are pointed. If we place the lower edge of the square upon a plane board so that the wires are in a horizontal position the point of the one wire, measuring from the board, must have the highth as indicated in the drawing from the bottom frame to the turning point of the hammer shank. The point of the other wire measuring from the board must correspond in highth with the distance between the bottom frame and escapement lever rocker in the drawing. As the action is fitted on the key frame outside of the piano, we take a board large enough to represent the bottom frame of the grand and place the key frame upon it.

Put the action on the props of the key frame. Placing the lower edge of the square on the board and arranging the action so that the point of the one wire points directly to the turning point of the hammer shank, the point of the other to the turning point of the escapement lever rocker, we can determine the highth of the position of the action exactly according to the directions of the drawing. It is a matter of course that the wires must be so long that their points can touch these turning points. If the highth from the bottom frame up to the strings is kept exactly the same in all grands built afterwards, also the length of the hammer heads and the borings for the hammer shanks, the square and wires may be used for all actions to be fitted. If however the measurement of the highth of the strings from the bottom board is to be changed, the two stationary points remain unchanged measuring from the strings, the wires must then be placed so much higher or lower as the difference in the highth of the strings from the bottom frame demands.

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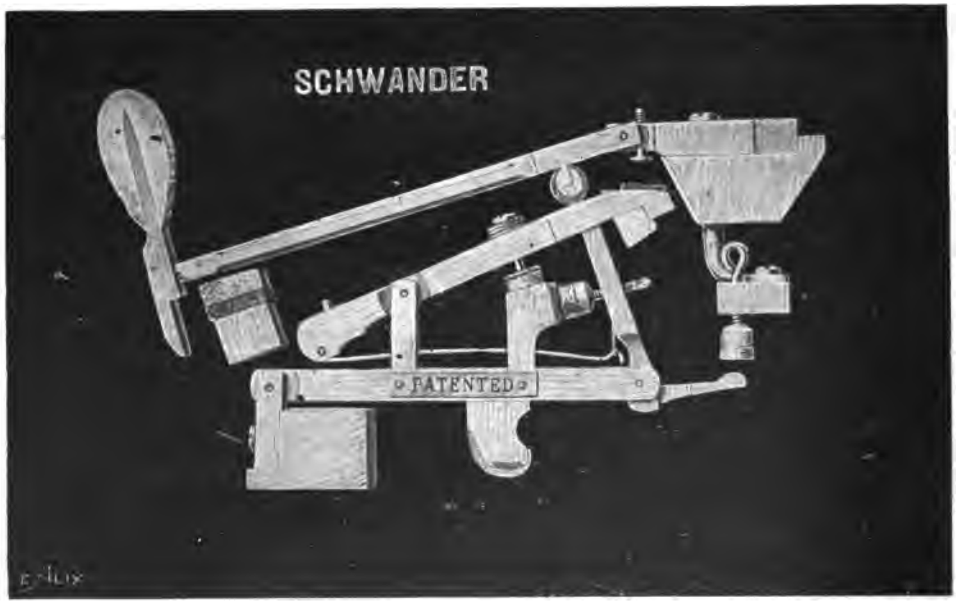

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Chapter XIV.

Transmission of sound.

Tone or sound is not alone transmitted through solids and fluids, but also through gases. The velocity of sound is in proportion to the elasticity and density of a body, being greater in bodies which are more elastic than dense, and *vice versâ*. Although this rule applies also to solids, the structure of the body must be considered. For instance, the velocity of sound in pine wood being 3324 mètres along the fibres, it has 1406 mètres across the rings, and along the same only 794 mètres. The velocity of sound is greater in solids than in the air, being for instance ten times greater across the rings of pine, seventeen times greater in iron and sixteen times greater in steel. Velocity of sound in the air is computed to be 333 mètres. The velocity of sound is specially great in hydrogen, one of the gases, for therein it is like in water, four times greater than in the air. The proportion of the elasticity to the density must be greater in solids than in fluids and aeriform bodies, for the reason that the velocity is greatest in solids.

We do not judge the goodness of sound conductors by the velocity of the transmission, but rather by the strength of the sound; hereby air may be considered the best conductor of sound. Although the strength of sound in the aerial body depends upon the density of the air; for a great decrease in the strength of sound is noticeable at certain heights on mountains, the air being rarer there than in the valley' Yet the goodness of a sound conductor depends far more upon the matter or substance of the body. Thus, sound has enough strengh for its existence in air under a pressure of only $\frac{1}{15}$

atmosphere, whereas sound is scarcely audible in hydrogen brought to the density of the pressure of an atmosphere.

Sound is transmitted with equal rapidity through dense and rare, but not through cold and warm air. Every increase or decrease in temperature of one degree centigrade will increase or decrease the velocity of sound by 0·6 mètres. Thus, sound is more rapidly transmitted through warm air than cold; whereas the velocity of sound of high and low tones is equal. Were the latter not the case, music heard from a distance would be disconnected, and therefore not intelligible. Sound transmission is strongest in the direction in which the sound is given; and, being unhindered in its propagation, will decrease in an inverse quadratic proportion to the distance of its progress. However, if the air be confined within certain bounds—for example, in a tube—the diminution of the sound's strength will be much less for the same distance. We know, for instance, that for this reason the music of horns is far pleasanter in the open air than in a room, where the full unhindered strength of the tones affects the auditory nerve most unpleasantly.

The circumstance that sound is considerably weakened in transmission from a lighter into a heavier body, is worthy of remark to pianoforte makers; if, however, the reverse is the case, so that sound goes from a heavy into a light body, its strength remains unaltered. The report of a cannon from the valley is heard with the same strength by one standing at a certain elevation on a mountain as by those standing at a relative distance in the valley, although the sound passes from a heavy into a lighter body. If the cannon were discharged on the summit of the mountain, the sound, passing from a light or rare body into a heavier or denser one, would be weakened considerably more on its way toward the valley than in the horizontal direction wherein it travels through an evenly dense body. The diminution in the strength of sound is still more remarkable if a wall of rock should intervene between us and the explosion, for then the medium through which the sound passes is much denser than before. This phenomenon is well known to us all, so that it ought barely to require mention; and yet it is so often disregarded in pianoforte making.

In the first half of the last century, Streicher, an intelligent piano maker of Vienna, recognised the great advantage obtained by discarding the full bottom-board of grands and using instead the so-called posts. Other piano makers likewise recognised the advantage, and so to-day we find this principle followed not alone with grands but also with upright pianos. From time to time, piano makers, disregarding this advantage, conceive the idea that the chief or principal sounding-board should be separated from the outer air by means of a second sounding-board, thereby to enlarge the tone. However, an enclosed space is created between the two boards, and the tone must travel from the confined air through the second sounding-board,—i.e., from a light into a denser medium in order to reach the outer air and must therefore be weakened in a considerable degree upon gaining it.

The question might here arise whether the power of the tone would be enhanced more so than by free propagation if the volume of the enclosed space were directly connected with the outer air by means of an opening. No! To augment tone by means of an air column, the latter must be applied as a direct resonant body, much like with organ pipes, and is not to be achieved with columns of air in the piano. The idea of the musician Zachariæ to augment the tone of pianofortes by air columns proved a complete failure. Had Zachariæ witnessed the countless experiments which have been made with air columns he would long since have recognised the impossibility of executing his designs, and would have relinquished his idea.

No pianoforte maker can have sacrificed more time, trouble and money for this unhappy idea than I did; still, no one can have derived more beneficial lessons therefrom than I. The conclusion gained by me from attempts to employ columns of air in the pianoforte is that the sounding-board in common must be dispensed with, and each set of strings—i.e., every set of three strings pertaining to one tone—receives an air chamber according to the pitch. The resonance, however, which the three strings of a tone receive from such an air chamber is considerably less than that given to them by the sounding-board in common of all the strings, and its effect on the treble tones is equal to nothing. Apart from the fact that such a piano, being about six mètres broad, with all the evils of the action, must also always be exactly in pitch, the strings cannot support each other as they do when they have a sounding-board in common. The beats are so feeble that it were well to use tuning forks; and, as a six mètre broad tuning fork piano with a 32ft. air column is not fit for a parlour, it were just as well to build a small church organ.

After the foregoing deviation from the subject, let us revert to the transmission of sound in the air and let us closely study the real nature of sound transmission. Hear Tyndall's opinion, which embodies Helmholtz's theory. Tyndall in his work on Sound, p. 32-34, says:—

"Applying a flame to a small collodion balloon which contains a mixture of oxygen and hydrogen, the gases explode, and every ear in this room is conscious of a shock, which we name a sound. How was this shock transmitted from the balloon to our organs of hearing? Have the exploding gases shot the air particles against the auditory nerve as a gun shoots a ball against a target? No doubt, in the neighbourhood of the balloon there is to some extent a propulsion of particles; but no particle of air from the vicinity of the balloon reached the ear of any person here present. The process was this. When the flame touched the mixed gases they combined chemically, and their union was accompanied by the development of intense heat. The heated air expanded suddenly, forcing the surrounding air violently away on all sides. This motion of the air close to the balloon was rapidly imparted to that a little further off, the air first set in motion coming at the same time to rest. The air, at a little distance, passed its motion on to the air at a greater distance, and came also in its turn to rest. Thus each shell of air, if I may use the term, surrounding the balloon took up the motion of the shell next preceding and transmitted it to the next succeeding shell, the motion being thus propagated as a *pulse* or *wave* through the air.

"The motion of the pulse must not be confounded with the motion of the particles which at any moment constitute the pulse. For while the wave moves forward through considerable distances, each particle of air makes only a small excursion to and fro.

"The process may be rudely represented by the propagation of motion through a row of glass balls, such as are employed in the game of solitaire. Placing the balls along a groove thus (Fig. 1), each of them touching its neighbour, and urging one of them against the end of the row, the motion thus imparted to the first ball is delivered up to the second, the motion of the second is delivered up to the third, the motion of the third is imparted to the fourth, each ball after having given up its motion returning itself to rest. The last ball only of the row flies away. In a similar way is sound conveyed from particle to particle through the air. The particles which fill the cavity of the ear are finally driven against the tympanic membrane, which is stretched across the passage leading from the external air toward the brain. This membrane, which closes outwardly the drum of the ear, is thrown into vibration, its motion is transmitted to the ends of the auditory nerve, and afterward along that nerve to the brain, where the vibrations are transmitted into sound. How it is that the motion of the nervous matter can thus excite consciousness of sound is a mystery which the human mind cannot fathom."

So far it might far sooner be possible that the case is as Tyndall states it if the particles of air were really such hard bodies as the glass balls of the experiment. Desiring, for instance, to fathom the tone development of a steel string, we surely cannot do so by experimenting with eiderdown. The air is capable of expansion, and so extremely elastic a body that it is not capable of a molecular shock effect as Tyndall wishes to explain it. We are tempted to disbelieve such an effect in observing water: how much more so with the aërial body. The air mass is so coherent that one molecule cannot impinge upon another. When Tyndall speaks of exploding gases that shock the air, this is perfectly clear to us; however, in speaking of a sound movement in the air, it is to be believed that facts differ entirely from his opinion. Tyndall also writes:—

"The propagation of sound may be illustrated by another homely but useful illustration. I have here five young assistants

—A, B, C, D and E, Fig. 2—placed in a row, one behind the other, each boy's hands resting against the back of the boy in front of him. E is now foremost, and A finishes the row behind. I suddenly push A, A pushes B and again regains his upright position; B pushes C; C pushes D; D pushes E; each boy, after the transmission of the push, becoming himself erect. E, having nobody in front, is thrown forward. Had he been standing on the edge of a precipice, he would have fallen over; had he stood in contact with a window, he would have broken the glass; had he been close to a drumhead, he would have shaken the drum. We could thus transmit a push through a row of over a hundred boys, each particular boy, however, only swaying to and fro. Thus also we send sound through the air, and shake the drum of a distant ear, while each particular particle of the air concerned in the transmission of the pulse makes only a small oscillation.“

The fitness which Tyndall thinks to find in these two examples results from a wrong conception. Why does Tyndall not allow the boys to stand close together instead of placing them a foot's length apart? Or, are the particles of air not closely together? Let us put this example into a little different form. In the days of my youth I stood for hours in the crowd before the Opera House in Berlin, awaiting the opening of the doors. There were always some young folks who delighted in setting this mass of people into a swaying motion. He who stood in the crowd was bound to this movement. It was a wave which ever returned into itself. However, there was not the slightest sign of one person knocking against another, for the possibility of such an act was prevented by the denseness of the crowd.

Tyndall writes furthermore:—

“A very instructive mode of illustrating the transmission of a sound pulse is furnished by the apparatus represented in Fig. 3, devised by my assistant Mr. Cottrell. It consists of a series of wooden balls separated from each other by spiral springs. On striking the knob A, a rod attached to it impinges upon the first ball B, which transmits its motion to C, thence it passes to E, and so on through the entire series. The arrival at D is announced by the shock of the terminal ball against the wood, or if we wish by the ringing of a bell. Here the elasticity of the air is represented by that of the springs. The pulse may be rendered slow enough to be followed by the eye."

Explaining the elasticity of the air with spiral springs and the intervening wooden balls which are to represent particles of air springing to and fro is, to say the least, an original conception of a body where there is not the slightest trace of such a springy elasticity. Hear the rest of the first section of Chapter I.:—

"Scientific education ought to teach us to see the invisible as well as the visible in nature, to picture with the vision of the mind those operations which entirely elude bodily vision; to look at the very atoms of matter in motion and at rest, and to follow them forth, without ever once losing sight of them, in the world of the senses, and see them there intregating themselves in natural phenomena. With regard to the point now under consideration, we must endeavour to form a definite image of a wave of sound. We ought to see mentally the air particles when urged outward by the explosion of our balloon crowding closely together; but, immediately behind this condensation, we ought to see the particles separated more widely apart. We must, in short, be able to seize the conception that a sonorous wave consists of two portions, in the one of which the air is more dense and in the other of which it is less dense than usual. A condensation and a rarefaction, then, are the two constituents of a wave of sound."

Having thus far followed Tyndall's explanation, we have obtained some idea of the prevalent theory of the transmission of sound in the air. Occasionally a voice is raised in refutation; so also has Professor Henry Mott of New York, in his work "The Fallacy of the Present Theory of Sound," disputed the validity of the above theory, but fails to substitute another. However, we are not satisfied with a refutation which offers no compensation. So much is certain: sound is transmitted in the air by means of some motion, because transmission could not even be imagined without movement. To obtain a clear conception of the invisible process of sound transmission in the air, we will separate the probable from the improbable, hereby closely testing and considering all the particulars of the material at our disposal. First, we treat of the formation of the sound wave in the air. We allow that the same consists of a condensation and rarefaction or of a compression and expansion of the molecules in a longitudinal vibration. Every tone pitch has its special wave length in the air, and, namely, according to the calculation that, for example, C_2 having 16·166 beats per second, and the velocity of sound being 333 mètres during the same time, receives a wave length of 333 mètres divided by 16·166 = 20·5 mètres; thus the tone C having 4138·440 beats per second, receives a wave length of 333 mètres divided by 4138·440 = nearly 8 cm. Now, whence comes the power of the air wave to contract and expand 20·5 mètres? The report of exploding gases—whereby, as Tyndall states, the air is heated and must therefore expand—cannot be applied to sound, because, if heat were really generated with the phenomenon of tone, it would be too insignificant to exert any such influence upon the air. A violent advance of the molecules—or that they allow themselves to be compressed through the influence of the sound's shock, then to expand—is likewise not possible, for in this case the velocity of sound in the air could not possibly be 333 mètres per second.

We must not seek the medium by which the transmission of sound in different bodies is carried on in the power exerted by the sound wave, but far rather in the peculiarity of the bodies to be specially susceptible to sound.

We may here take into consideration the light phenomenon, which is likewise supposed to take place in vibrations. We cannot believe that a spark can travel forty-two thousand geographical miles in a second through an act of violence, and besides in a rectilinear transmission. The spark of light which travels the millions of miles from the sun so rectiliniarly can do so only through the attractive power of the earth; and, much like to sound with the telephone, it employes an electric vibratory path which here connects the two planets. If, beside the ear and the eye, we possessed an apparatus to measure the electric vibrations, mystery would vanish and we could estimate the vibratory forms and their power in natural simplicity.

The theory of sound transmission hitherto taught was that the agitated particles of air return to rest after one movement to and fro. According to this, the connection by means of the electric vibratory path between the sound's place of origin and us is lost, and we cannot tell from what direction a sound proceeds. The entire theory is in no wise valid. We know exactly which way to turn when some one calls us, unless the ear be deceived by some deviation of the vibratory path from its straight course by means of some intervening object, just as the eye may be deceived as to the location of some object seen through a window pane wherein there is a blister. The vibratory path of sound keeps a connection with its place of origin in the same way as does the light wave. If the light wave kept no connetion with its place of origin, objects seen at a distance and suddenly withdrawn from view would to all appearance come to us. Light and sound both keep a connection with their place of origin during transmission if the latter is carried on with a free propagation of the waves. The following may explain the process. According to the opinion of the entire learned world, if the sun suddenly disappear from the heavens, we have the pleasure of beholding it in the same spot fully eight minutes after this occurrence. How is it possible for us to see the sun, which really is not unchanged, in its place? It is not conceivable—let us say, possible—otherwise than through the wave which keeps a connection of the light spark with its place of origin.

Eight minutes after the above mentioned occurrence, we no longer see the sun, and night surrounds us; whereas a planet —which, for instance, is twice as far from the sun as is the earth—will bathe eight minutes longer in the light of the sun than does the earth; and, although we are still within range of the light vibrations, we cannot perceive the same as light because we are no longer exposed to the shock of the wave. So it is with sound. For instance, although we cannot recognise the location of a body with the same certainty with our ear as does the eye, still we know exactly whether a tone came from far or near, recognise the direction of the tone, &c. This would not be possible if the tone kept no connection with its place of origin. Persons still further from the sound producing body will hear the sound just as we did; and we, still standing within range of the vibratory path of the sound, will not hear it because we are no longer exposed to the shock of the vibratory path. It becomes ever more clearly evident that the vibratory path of sound is an electric phenomenon as well as the sound wave. But all this is merely a guide to coming theories. * The new generations will not abide by theories the unsoundness of which has long been felt: they will not cease to search and study. Thus there will be formed an endless chain through thousands of years; for, wherever science has thought one of nature's problems solved, another has arisen from the solution. Such we very often find the case with space acoustics. Not alone musicians and acousticians, but also every builder of musical instruments will be interested in space acoustics. But here let the little suffice which the writer says of space acoustics and its related phenomena in the following chapter.

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* The time seems to be near at hand when such theories will be adopted. Strassburger papers write (Jan. 8, 1904) as follows:—

"Professor Braun announced in the 'Naturwissenschaftlichen Verein' that he succeeded, by means of experiments based on the Herty's Vibratory Phenomena, to prove light to consist of electric vibrations."

* * *

Chapter XV.

Acoustics of space.

Every enclosed space will, more or less, show certain acoustic peculiarities. Musicians and piano makers have observed these phenomena, failing to comprehend the cause thereof. It would not sound strange to any one were I to say that a certain room has a good or a poor resonance. I am confident that the idea would be conveyed to all that the acoustics of the room were meant; and yet there is a vast difference between the acoustics and the resonance of a room or space. The question might be put, „Will the walls, ceiling, &c., of a room in which a body is made to sound, resound?“ No! To ascertain how the acoustics and resonance of a room differ, we place a musical box on a table. As soon as the mechanism of the box is set in motion, we discern from the augmentation of tone that the table top serves the musical box as resonator. Placing the box against the door panel, everyone will recognise that now the door panel and not the table top is the resonant body which augments the tone. Holding the box free in one's hand, the decreased tone fulness proves to us that neither the table top nor the door panel are resounding. We see that a body must be directly connected with the tone producer in order to resound.

Before we treat of the room's acoustics, let us examine the various objects in it as to their resonance. We will find that the walls are not numbered among the best resonators. We suppose the room to be furnished with many objects capable of resonance. In stripping the room of various objects, we observe that the tone of the musical box increases as the room is emptied. Even those objects which would give an excellent resonance have had a damping effect on the tone; the best acoustic is found in an empty room. In an empty room tone waves can propagate more freely than when various objects obstruct their way; there being no intervening medium, they reach the walls unweakened and are reflected by the same. Although room acoustics and resonance alike increase tone, we recognise that the nature of one differs vastly from that of the other. These two qualities also show different effects in regard to substance or matter employed; so, for instance, those bodies specially adapted to resonance are not equally available for room acoustics. We have learnt that pine wood gives the best resonant bodies; still, it has been observed at an Industry and Trade Exhibition, where instruments were placed in wooden stalls, that wood is not specially good for room acoustic, because it is capable of taking up and absorbing a portion of the sound waves.

Some musicians have asserted that, through the resonance of a number of violin bellies hung in a room, the acoustics of the room would be remarkably augmented. I contradicted this. The gentlemen were astonished that a pianoforte maker could be so deficient in his knowledge, and therefore a test was made in their presence. Lacking a large number of violins without strings, numerous cigar boxes were hung from the ceiling of the room. The tone of the piano used for the experiment was so markedly damped or dulled by the arrangement that all were thoroughly convinced that the best acoustics exist in an empty room.

Stone buildings are found to have much better acoustic properties than wooden ones. Judging from the acoustics in various stone buildings, we come to the conclusion that quarried stone is superior to brick. The materials, or the peculiarity of the matter of the bodies used in building the room, are of great importance for acoustics. Some examples follow with which the style or mode of building has nothing to do. Who has not observed that a hand organ in the street sounds better and louder on a clear day than it does on a damp and dreary day. In this instance, acoustic effects usually assigned to peculiarities in construction or build are due solely to matter or substance. We find that the acoustic properties are better favoured by the night time than by day; and it is known that at night an entirely different combination of the substances of the aërial body exists than when the latter is affected by daylight. Humboldt's experience will partially refute the view that attributes this phenomenon to the greater stillness of night and the heightened attention of the ear. Humboldt asserts that from a place in the Antures Valley one can hear the sound of the great Orinoco Falls much more distinctly at night than in the day time. He says: "This is not due to the stillness of the night, for the hum of insects and the bellowings of wild beasts make the night less quiet than the day." The writer knows from personal experience that an echo in the vicinity of Bad Eilsen, Germany, repeats much louder at night than in the day. Some assert that this phenomenon is caused by the change from a warm to a cold temperature; however, that cannot be. For instance, the echo at Woodstock Park repeats seventeen syllables in the day and twenty in the night. As the night is often warmer than the day, should not a correspondingly reversed action of the echo be noted at such times? During many years the writer has given his attention to this matter whenever an opportunity presented itself, which happens frequently during the winter, when the change of temperature is often very abrupt even during the hours of day. If the change from warm to cold air really influenced the acoustic properties as much as is generally stated and believed, it would be specially apparent at such times.

However, it seems far more to be matter or substance which influences acoustic properties than a change of temperature. Thus, the acoustic properties of rooms hung with furs or woollen draperies become much weaker. The cause of this phenomenon lies in the fact that such materials swallow and stifle the tone waves. Removing the draperies, &c., so that we have four naked, smooth walls, we obtain a decidedly augmented acoustic property, because the tone waves are reflected. We may assume that the tone waves are far too weak to break themselves against a wall and then resume their course in an opposite direction;

rather must it be the matter of the bodies which comes in contact with the tone waves that helps to render a reflection possible.

Experiments with mirrors have shown that the reflection of sound-waves is similar to that of light-waves. However, the reflection of light-waves is entirely dependent on the matter of the reflecting body. Light-waves do not break against a wall; rather are they thrown back or reflected by the wall when striking it. To illustrate we select two walls, one black, the other white: the black wall absorbs and smothers the light-waves while the white surface reflects the rays falling upon it. If light-waves broke against surfaces which they strike this would occour alike upon black walls and white ones. As this is not the case we may unhesitatingly assume that the matter of the colouring substance reflects (or does not reflect) the light-waves. The reflection of tone-waves is similar. Just as light-waves are reflected in the same angle at which they strike the wall, so are tone-waves returned in the same angle at which they fall upon the reflector. The reflected light-waves produce no apparition but merely an intensified light' reflected tone-waves give no new sound but an augmented tone. It is not, as is generally believed, the slight space between walls that prevents the returning tone-waves from giving a separate sound, but the strength of the latter does not suffice to surpass the direct waves; then too, a reverberation of sound is often found in rooms and halls. How is the possibility of sound-reverberation in rooms, offered? The question is easily answered:—A reverberation of sound will be created in a room when opposite walls correspond. Correspondence of walls may be facilitated by the mode of building; it is necessary above all else to chose material for the walls, which is susceptible of tonal vibrations. There is no doubt that such a correspondence does exist because it is impossible to create reverberation of sound with but one wall. Through construction or mode of building tone-waves may be conducted more or less to a certain spot, for tone-waves, like light-waves may be concentrated to a focus, or like these, separated. Thus tone-waves and light-waves are affected alike by vaulted ceilings. Many examples exist which show the influence of such structure. A few may serve as illustrations here: — "In the whispering-gallery of St. Paul's, the faintest sound is conveyed from one side to another of the dome, but is not heard at any intermediate point." (Tyndall.) This phenomenon is caused by the elliptic form of the vault. The Observatory in Paris contains a room purposely built elliptically vaulted and the two focuses of the ellipse produce similar effects. The same is noted in the vault of "The Ear of Dyonisius" in the quarries of Syracuse. The vault is said to have been a prison in olden times; the whispered conversation of its prisoners was plainly audible to the keepers.—We are acquainted with the construction and the workings of reflectors used in orchestras." In Gloucester Cathedral, a gallery of an octagonal form conveys a whisper seventy-five feet across the nave." (Tyndall.) If in the foregoing instances, the tone-waves are held together by means of the construction, reverberations or echoes may be surpressed in rooms by erecting contrivances which will break and disperse the direct waves before they reach the walls. In relation to this the "Music Instrumenten-Zeitung" (December 18, 1897) writes as follows:—

"Concerning the much debated question whether long houses or central buildings, of round or of quadratic ground-plan ought to be employed for concert halls, churches etc., A. Sturmhoefel expresses himself in favour of the former as used by the famous architects Zwirner and Boisserée around the middle of this century but which has been much avoided for the sake of lighter architectonic. The simple square is most appropriate for acoustic purposes; flat, expanded surfaces have a harmful effect on the distinctness of that which is offered because the sound is thrown back forcibly by them, all at once striking the ear of the hearer, in a most annoying manner, in the form of a reverberation. It is expedient to provide such surfaces with heavy relief by which the sound-waves are thrown back in various directions and at various lengths, so that they are percepted at different times by the auditors."

So far may construction work and regulate, but the sound-production consisting of reverberation or resounding, can never arise from it but is caused rather by the building-material: two illustrations follow:—"At Carisbrook Castle, in the Isle of Wight, is a well two hundred and ten feet deep and twelve wide. The interior is lined by smooth masonry; when a pin is dropped into the well it is distinctly heard to strike the water. Shouting or coughing into this well produces a resonant ring of some duration." Thus Tyndall writes of the instances of echoes collected by Sir John Herschel and adds the account of a similar instance in a note on page 49 "Sound":—"Placing himself close to the upper part of the wall of the London Colosseum, a circular building one hundred and thirty feet in diameter, Mr. Wheatstone found a word pronounced to be repeated a great many times. A single exclamation appeared like a peal of laughter, while the tearing of a piece of paper was like the patter of hail."

It is comprehensible that tone-waves cannot penetrate, for instance a wall, without a special procedure. A similar phenomenon is found with light-waves, and by means of this we will try to approach facts. How is it, that objects which are on the light side of a windowpane are also seen on the other side of the same? Light-waves can no more pierce so dense and hard a body as glass, than they could a board: it is quite as impossible for tone-waves to do so. The composing-material of glass has the property of absorbing light-waves. But, can these waves, which in themselves are not matter, be *absorbed?* Far better is it said that a glass-body, with the aid of its matter, which takes up the motion of light-waves, is capable of transmitting light in itself, and of emitting it on the other, darker, side. According to science, light-ether penetrates all things, so that through this, light can penetrate all bodies in a lesser or greater degree. This view may partly be right, but, since sheet-iron is more porous than glass, rays of light should be able to penetrate the former more readily than the latter. We find that the property of glass to transmit light-waves, must be sought especially in the composition of the body's matter. Most assuredly the polish or smoothness which glass possesses through and through, assists in keeping the light-waves in the greatest perfection thus to form the reflection on the other side: but there are other bodies (for example flint) which are smooth throughout but do not share the property of glass. Hearing a tone which has reached us through an intervening wall, it would be erroneous to suppose that the tone-waves could pass through the pores by means of the air with which the latter are filled; in this instance the wall must enter into the motion of the tone-body, which it will do in the same degree as its matter is susceptible of tonal vibrations.

Glass is not alone capable of creating a mirrored picture on its dark side but, by reflection of the light-waves in the glass, such an image may also be formed on the light-side. In an ordinary mirror for instance, the reflection is effected by quicksilver which is put on the dark side of the glass. Here we may see that quicksilver does not *absorb* light-waves but only reflects them, for, were but a minute part of the light-waves absorbed, the image would become imperfect. Thus we have ample proof of the susceptibility of some matter for light-waves, and of the resistance of other matter against them.

As tone shows phenomena similar to those of light, we seek the causes of these phenomena in the *matter* of bodies, and not in their construction. Just as reflected light-waves produce a mirrored picture on the light-side of glass, tone-waves may produce a "mirrored tone" with similar phenomenon. We met this "mirrored tone" in treating of reverberation and there is but little more to be noted with the *echo.*

In all cases of reverberation in rooms we observed that if the reflected tone-waves are to produce a separate sound two opposite walls must correspond. If echoes consisted of simply reflected tone-waves (as it has hitherto been believed) they would be innumerable for every building every wall of rock, and many other similar objects at which we would speak from a certain distance, would give an echo.

To produce an echo, the speaker must stand from the tone-reflector at a distance according to the number of syllables which the echo is capable of repeating. We can distinguish ten tones or three syllables in one second of time. A tone travels 340 metres in a second at 10° C. — An echo of two syllables would therefore require $\frac{2}{3}$ of a second in order to be distinguished; the sound would travel ⅔ of 340 metres = 226⅓ metres in ⅔ of a second. A reflected tone or sound has to travel to the tone-reflector and back to its origin. Therefore, if two syllables of an echo are to be distinguished in ⅔ seconds, the tone-reflector must be stationed at least ½ of 226⅓ metres = 113 metres from the source of the sound or tone. A powerful male voice can be heard at a distance of 240—280 metres at most. Calculating with normal proportions, simple reflected waves could barely reach the standing point of the speaker. But what is the journey of a two-syllable echo compared to the Woodstock Park echo which repeats twenty syllables? The tone-reflector of this echo must be stationed at least 1133 metres from the speaker; the entire journey of a sound-wave is accordingly 2266 metres. A peculiarity of the Woodstock echo is that it repeats only seventeen syllables by day, the station of the speaker remainning unchanged.

We see that there is much, still hidden in obscurity with the echo, and that, like in the foregoing instance, there is much in Nature's great work-shop to be sought and revealed. Wonders there are none, although it seemed a mystery to us when first the intelligence reached us that sound-waves were being carried to distant places by means of electricity i. e. of electric vibrations, and that these sound-waves were recognized there. Were the proof not given us with our own ears at the telephone, we might still doubt. Just so with the phonograph upon which tones and sounds are registered, (one may say in the simplest manner,) ready for reproduction at any moment.

Chapter XVI.

Interferences in the rhythmical motion of sounding bodies.

We have all observed that two corresponding tones do not always strengthen, but under circumstances decrease, or temporarily suppress each other. Young called this phenomenon "Interference" and scientists have retained this term. In the chapter on Overtones it is stated that when many unequal tuning-forks are affixed to a sounding-board, the latter may refuse to act for the reason that no rhythmic motion exists. Placing two tuning-forks of unequal vibrations upon a sounding-board a disturbance in the rhythmical motion also ensues, but as the sounding-board is stronger than the forks, the disturbance is more noticeable upon the latter than on the board. Every tuner knows from experience that when it is impossible to bring the three strings producing a tone, into perfect unison, the trouble lies in a defective rhythmic motion of the same. There are pianos in which a defective rhythmic motion is so apparent that it is almost impossible to bring a single group of strings (Chorsaiten) into unison: the trouble is caused by a defective sounding-board or a faulty stringing etc. A careful observer may note that a piano with a weak sounding-board and unevenly distributed ribs, will allow a singly struck tone alternately to swell and sink. Science teaches that the wave motions of two tones going in the same direction are capable of destroying each other temporarily, if the elevation of one wave fills the depression of another, so that an equalization ensues which may caüse a momentary cessation of tone: just so can two waves be mutually supporting if they coincide, whereby we obtain an augmentation or swelling of tone. This part of the wave theory has never been quite comprehensible for me, nor can the process be accomplished by practical experiments with water waves. These phenomena do not arise with the wave-motion in the aerial body but come directly from the sounding body or from the resonant body, in such a manner that through an unequal rhythmic motion of two bodies, the weaker may be brought to a momentary standstill. For various experiments I employed, among other objects, long, elastic sticks cut from sounding-board wood. In trying to influence the vibrations of such a stick through weights, a rather singular experiment fell into my hands. One end of the stick was secured; from the other a weight was suspended by a string, so that it could sway independently to and fro. It was impossible to regulate the vibrations of the stick for the independent swinging of the weight would not permit it. I endeavored to make the movements of the stick conform to those of the weight and to this end shortened the stick. Before acquiring the desired conformity I witnessed a noteworthy phenomenon; the stick voluntarily set itself in motion according to the swinging of the weight: the vibrations of the stick were double in number to the oscillations of the weight. Nine vibrations were made by the stick and then it stood still; it paused for a time equal to five of its vibrations and this occured as often as it performed nine vibrations. Had this phenomenon taken place with a sounding body where a wire string takes the place of the cord by which the weight is suspended and a sounding-board represents the stick, the process would have been manifested in the tone, i. e. the tone would have seemed to augment and decrease by turns. It is a fact that we find such tones with many pianos where every diminishing of tone is succeeded by a jerky augmentation. Some pianomakers consider this an extraordinary singing quality of the instrument. This is not to say that rhythmic disturbances cannot occur in the aërial body but these never arise in a manner as scientists believe them to do. No one has as yet been able to prove how rhythmical vibrations of a body are taken up and transmitted by the aërial body.

The pianomaker may learn from the foregoing how necessary it is to make correct foundations for the vibrations of both strings and sounding-board. The rhythmic motion of a body requires a symmetry of the separate members and this is to be achieved by mature reflections, accurate trials and examinations.

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Chapter XVII.

The repairing of various pianos.

In adding this chapter to "The pianoforte in its acoustic properties," I have been led by the opinion of various persons who deem it of great importance and advantage to piano manufacturing to train people to do piano repairing. Experience has shown that it is necessary to have people who know how to handle and keep pianos in order, in all places where pianos are to be introduced. Asia, Africa, Australia and America offer new fields for the sale of pianos, and in many remote regions in these countries there are pianos requiring repairs. The piano business cannot be taken up professionally in such places; so self-aid becomes necessary, and written instructions will prove a real benefit to people in these regions.

Many of those who have learnt piano-making according to directions and practical instructions will doubt that an untrained person can repair pianos in a very satisfactory manner, having acquired the requisite information from a book only. Nevertheless, there are persons who, without previous practical instruction, have made all manner of repairs on violins, pianos, &c., evincing great skill and accuracy.

Persons selecting piano-repairing as a vocation should avail themselves of any opportunity offered whereby they can practically learn the business, and should bear in mind that it is of priceless value to have the benefit of a master's experience. The teacher will not alone instruct his pupil in the practical manipulation, but will also transmit to him that experience necessary for independent practice in any trade, whereby much time and trouble is spared the learner.

It is specially important that the amateur should be acquainted and made familiar with the different tools and materials required for repairing a piano. If piano makers appreciate the catalogues of various supply houses, which have been issued during the last few years and which contain perfect representations of materials and tools, how much more will they be prized by those who have worked with imperfect tools because the better ones were unknown to them?

May the reader pardon that the mechanical parts of. the instrument are almost exclusively mentioned and the exterior well-nigh ignored: there is a carpenter or cabinet-maker in almost every locality, who can remedy any defects on the piano-case. I also wish to avoid a long record of the things which may eventually rattle and jingle in a piano. If such disturbances arise while playing the piano, the locality of the evil must first be ascertained. This problem cannot be solved by means of written instructions, because, perhaps, among a hundred explanations not one would suit a special case. Sometimes an experienced piano maker cannot immediately locate the seat of the disturbance, and must search long and patiently before he can remedy the evil. Here, too, "Practice makes the master." Of what advantage would it be to an amateur if he were told that, if such or such an action part becomes loosened, causing noise, this or that screw must be fastened! Surely everyone who has found the seat of such an evil, can also remedy it without further instruction. Some noises may be avoided by making sure that every part of the piano is properly and firmly adjusted in its place, Move the piano a little, and ascertain whether the noise may not be occasioned by something outside of the piano; perhaps, too, one of the four casters may not have been firmly placed on the floor. For further instructions I recommend the book, "Construction, Tuning, and Care of the Pianoforte," by Edward Quincy Norton. The same may be obtained of Oliver Ditson and Co., Boston, Mass. It is my sincere wish that the contents of this chapter may prove of service to those, especially, who, relying on their inborn capabilities, undertake the repairing of a piano.

REPAIRING ON SQUARE PIANOS.

After removing the top of the piano, the next step is to take out the damper cap rail; the damper flange rail, with its damper lever, must also be removed. The damper lifters are thereby laid bare; they must be taken out singly, and in succession, and placed thus on a board. If there is no damper flange rail, the damper lifter wires pass singly, each through a separate hole which is either in the wrestplank or in the iron plate, and are fastened to the damper lever in the interior of the action-room. Unless the holes require new felt lining, the dampers may remain undisturbed in their places.

The action must be removed from the piano. If the action is fastened by means of screws which go through the bottom of the bottom-board (also called key-board), then the action is ready to be taken from the piano after these screws have been removed by means of a tuning hammer. Should the screws not be there, the key-slip must be removed by pushing it up, and the screws will then be found in the front-piece of the key-frame. If, however, the key-slip is glued to the key-frame, then the name-board must be lifted from its position, whereby the action is laid free for removal. These three different arrangements may be considered as being in general use; but there are deviations from them in exceptional cases. Before undertaking any other step, the piano should be thoroughly cleaned of dirt and dust.

If the instrument is to have a new stringing, care must be taken in removing the covered strings that these are hung in succession by their loops on a strong string or wire. Should a covered string be missing here and there, make a loop on a good piece of twine, and mark with ink the places where the covering-wire begins and ends. This twine is hung in place of the covered string among the rest. These measured pieces of twine are used as patterns, and any piano supply-house will furnish covering-wire according to it. If the old uncovered strings are to be replaced by new ones, care must be taken to keep the original proportions of thickness, for these proportions have been chosen by the maker of the instrument according to those of other acoustic parts (for instance, according to the sounding-board, the hammer-covering, &c). The strings are measured by means of a music-wire gauge, and the result noted. In many cases the numbers of the music-wires are marked between the tuning pins, or on the notches of the sounding-board.

In case the tuning-pins in the tuning-block become loose, a thicker number must be used. If one thinks that it is not advisable to use thicker and longer tuning-pins, or that the wood of the tuning-pin block is no longer firm enough, and if one does not wish to put in a new block, then it is best to remove the tuning-pins and to enlarge the holes by means of a bore somewhat larger than the thickness of the tuning-pins. The holes are then plugged up with maple wood. The plugs must be driven so far into the holes that in boring holes again for the pins, the bore need not reach the end of the plug. The plugs must be so thick, too, that the tuning-pins do not come in contact with the glue with which the plugs were fastened into the holes. The bore to be used for the holes which are to receive the new tuning-pins must be selected according to the required width of the hole; this width may be ascertained by screwing in one tuning-pin. The tuning-pins must pass firmly into the holes; however, with old pianos, care must be taken not to drive the pins too tightly into the wrest-plank. If a tuning-pin should break in the wrest-plank, so that it cannot be removed by means of the tuning-hammer, use a tuning-pin extractor.

After the strings have been removed, clean the sounding-board and iron-frame, using a sponge and clear water. Under no considerations should alcohol be used to clean parts that have been varnished, for the consequence may be that the dirt will mix with the varnish, which is soluble in alcohol, and thus give the varnished parts a miserable appearance. If the dirt has settled in places so that it cannot be removed with clear water, use warm water with a little soap and soda. The wooden parts must then be dried as quickly as possible with a cloth. In order to restore the gloss and freshness to the varnish, for instance, on the sounding-board, iron plate, &c., rub these parts with a little polishing-oil or olive-oil. Rub so that the oil is removed again.

After all parts have been carefully cleaned, ascertain if tuning-block, sounding-board, &c., are still firmly connected with the instrument, and where defective parts are found, try how far the loosened members can be separated. The openings must be carefully cleaned before they are filled with hot glue, closed with handscrews, &c., for glue does not bind wood to wood when dirt and dust have collected in the joints. If possible, the wooden parts which are to be glued, should be made rough by means of a tooth-iron; hereby the old glue is removed and the fresh glue has new surfaces to combine. One should never forget to furnish freshly-glued parts in old pianos with screws, wherever it is possible.

Cracks in the sounding-board may be mended by filling them with chips of spruce. Widen these cracks by forcing a knife into them and drawing it through the entire opening. The chips must be cut so that one edge is thicker than the other. When the thinner edge fits snugly into the opening of the crack, hammer the chip along its length, so that it may be placed more easily into the opening of the crack. After glue has been put into the crack, the warmed chip is driven into the opening. If now, real hot water is brushed along both sides of the chip, it will swell to the size it had before being hammered, and will then fill the crack perfectly. After washing away all the glue from the sounding-board, the chip must be left to dry for twenty-four hours before it is cut even with the surface of the sounding-board by means of a sharp instrument. Do not use sand-paper in levelling the chip, because those places in which the sand-paper grazes the sandarach with which the sounding-board is coated, take a peculiar colouring, and thus give the sounding-board a spotted appearance.

It often occurs, especially with square pianos, that the sounding-board bridge cracks in places in the bridge-pin line, rendering the pins so loose that they can be removed without the use of tools. In such places, remove strings and bridge-pins; take a piece of white paper, place it on the damaged part, and rub back and forth with a broadly-held lead pencil until the form of the bridge and of the bridge-pin holes is visible on the paper. Complete the places where cracks hindered the bridge-pin holes from being perfectly marked on the paper, by means of a compasses. This paper is the pattern for the new wooden part to be inserted into the bridge. If the iron-bars and the space in the piano permit, the damaged parts on the bridge must be cut to the depth of 1 c.m. in various places, by means of a small-saw; if not, use a small, short piece of saw, affixing a block of wood for a handle: then remove the wood up to the cuts made by the saw. The cavity in the bridge must then be prepared for the insertion of a piece of quartered maple. Before gluing the piece of wood into its place, ascertain whether the holes for the bridge-pins can be bored and the bridge-pins inserted, after the wood has been glued; if not, the piece of wood must be prepared beforehand, and then glued. As a rule, the iron-bars in the piano prevent the work from being done inside the instrument. It is safest to secure the glued wood with a few screws, whose heads are driven so deeply into the wood that they may be covered by a bit of wood. The blacking of the upper edge of the bridge is done with pulverized blacklead, which is made into a stiff paste, by mixing it with water and vinegar, and is then applied with a stiff brush. To polish, rub with a smooth steel-iron, for instance, with the back of a hammer. To keep the bridge neat, the blackleading should be done after the holes for the bridge-pins have been bored; when the blackleading is done, the bridge may be notched.

If the old strings are not to be removed from the piano, but are covered with rust, smear machine-oil on them and leave them thus for twenty-four hours. After the oil has been removed, dip the end of a hammer shank into pulverized pumice stone, and rub the strings till they are bright. If the oil has not been well removed, it will mix with the pumice stone, and when the latter falls upon the sounding-board, the sandarach will eagerly absorb the oil, thus giving a spotted appearance to the sounding-board. To avoid this, spread paper on the sounding-board, whereupon all refuse from polishing the strings may fall.

The buffstop, which is arranged to cause a gentle pianissimo when used while playing the instrument, must be examined regarding its usefulness. If the felt strips are defective, they must be replaced by new ones. Buffstop felt and red leather in strips of about 86 c.m. length may be procured, ready for use, from any supply-house. The buffstop rail must move forward and backward, readily. Nothing is so disturbing for the player as a buffstop rail which, when used, moves sluggishly back and stops at half way. If the buffstop rail makes a drumming noise on the sounding-board while the piano is in action, most likely the leather under the buffstop rail has become hard, and must be substituted by real soft buckskin. Do not neglect to sprinkle soapstone on the buckskin, because this lessens the friction of the buffstop leather upon the sounding-board. The buffstop rail usually consists of two parts, and if the respective screws with which they are fastened are loosened, the parts may, with some care, be drawn separately from under the strings, and removed from the piano.

REPAIRING THE ACTION OF A SQUARE PIANO.

In repairing the action of a piano, the various parts must be examined, and, if any of them are in poor condition, they must be mended, or eventually renewed. The parts of actions in general use may be had separately from the supply-houses; the skill of the repairer is put to the test where an action, modelled differently, is used. The well-preserved parts of the action will serve as models, and give far better instructions as to repairing, &c., of separate parts than could be given here; whoever cannot work according to these models had better not attempt piano-repairing at all.

It is well to bear in mind that leather, cloth, and felt must be more pasted than glued with thick glue; these materials are not always glued along their entire surface, but sometimes only at certain distances. One may be directed, in this also, by well-preserved action parts. The ivory is also fastened to the keys by means of glue; if the front-piece of the keys are to be of celluloid, glue is also used to fasten these. It is advisable to add some ground chalk to the glue used on ivory and celluloid. In gluing ivory, the glue should be warmed by means of a heated piece of wood; as heat gives celluloid an ugly, wrinkled appearance, glue for celluloid should be treated in the same manner. It is, however, safest to use celluloid-glue for fastening any large surface of celluloid.

CAPPING HAMMERHEADS WITH BUCKSKIN.

Looking at an action in a much-used instrument, one instantly observes the deep furrows made in the felt by the stroke of the hammers on the resisting strings. The felt of the hammers must be removed to the depth of these furrows by a sand-paper file, whereby care must be taken to keep the hammers in shape. The file is made of a thin piece of wood (taken from the cover of a cigar-box, for instance) of about three-quarters of an inch wide, and any desired length; this strip of wood is covered by sand-paper No. 2. In American square pianos one usually finds the felt hammers from the middle of the action to the last treble hammers capped with buckskin. If the buckskin has become defective or hard it must be removed, and the hammer must be supplied with new caps. In order to spare the hammer felt as much as possible in removing the buckskin, try to cut the latter with a sharp penknife pushed underneath the capping, and then remove it carefully from both sides of the felt hammer. For capping the hammer, order "German piano-hammer capping-skin" of a supply-house; this skin may be obtained in brown, or yellow, with or without grain. If one does not wish to have the trouble of removing the grain which is on the under side, or the side that touches the felt, he must order skin without grain. It is not safe to leave the grain on the skin, because the tone may lose in quality hereby. Before cutting the skin into strips, its elasticity must be tested. Cut strips in the opposite direction to the skin's best elasticity, and as wide as required for the curve of the hammerheads. Smaller strips are now cut in the cross-cut of the original strip; these strips must be amply as wide as the hammers. If the strips are properly cut, the elasticity or bias is found in their length. The elasticity of the skin permits it to fit closely to the hammer, even in those places where it may not be glued. Edge or taper the little strips on both ends with a sharp knife; then, after assorting those for the thick hammers from those for the thinner hammers, the strips are fully prepared for capping. In capping a hammer, lay the middle of a strip on the vertex of the hammerhead, and then secure the sides to the curve of the same, which must be spread with glue beforehand. Hereby the strip must not be overtaxed in its expansion; to this end, rub the two ends or sides of the strip at the same time with the palms of the hands, from the top downwards, several times, thus pressing them closely to the glue-covered surface of the felt. In spreading the glue, do not put any of it on the crown of the hammer, that is, on that part of the hammer which is touched by the strings. To cap hammers, it is not necessary to remove them from the action; the hammer to be capped must be put into a position which elevates it above its neighbour. As glue takes some time to dry, so that the projecting buckskin cannot be removed at once with a knife, the hammers should be capped in two sets; that is, always skip one hammer, and when the glue on the first set is dry and the projecting buckskin is cut away, cap the second set in the same manner as the first.

If, after the piano has been regulated and tuned, one finds that the hammers are too hard, or that the felt hammers, after being filed with sand-paper, make the sound seem hard and rough, such hammers must be worked upon with a felt-picker. This tool may be made by sticking four needles half-way, and not too closely together, into a wooden handle. These needles must be stuck into the felt, respectively through the buckskin, until the required softer sound-quality is obtained. The picking of the felt by means of the picker is to take place on the crown of the hammerhead; the needles are brought into the felt in a direction somewhat diagonal to the perpendicular position of the hammerheads; afterwards, in equalizing the hammerheads for the evenness of tone, one may, if necessary, stick a picker of two or three needles a few times diagonally through the felt, but the needles should never be used from the sides of the hammers. Wool should not be allowed to collect on the surface of the hammers, because it has a damping effect on the strings, which results in a muffled sound; therefore, the needles have to prick the felt, but must not tear it to flakes on the surface.

BUSHING THE HOLES FOR THE CENTRE PINS.

For the purpose of lining the holes in the flanges, in which the centre pins have their movement, bushing-cloth is manufactured in different grades of thickness; thus, French scarlet bushing-cloth for actions may be obtained of a supply-house, 1, 5 m.m. thick, or medium 1 m.m. thick, or the thinnest of 0, 8 m.m. thickness. The thicknesses 1 m.m., and 0, 8 m.m., are used for the centre pin holes; the thickness 1, 5 m.m., and even 1 m.m., is used for the key bottom holes, in which the balance-rail pins conduct the movement of the key, and also for the holes of the key front pins.

If the hammer-butt flanges are supplied with a slit for putting the centre pins into the holes, cut a long strip of cloth to replace the old cloth, which must be removed from the slit. This strip must be somewhat wider than the strips taken from the slit are long. A wire, the diameter of which may be thinner than that of the centre pins in the hammer-butts, is placed along the length of the strip's smooth side, in such a manner that when the cloth is doubled or folded over, the wire will support the middle, or fold; thus the centre pins will come in contact with the smooth side of the cloth. The wire is wrapped into the cloth so that the hammer flanges may be strung by their openings on the strip. After having thus strung a number of flanges closely together on the strip, the slits must be securely screwed and the cloth glued to the fore-edge of the flanges. When the glue is dry, loosen the screws in the slits just enough to be able to remove the wire from the side. After the slits have again been tightly closed, the flanges may be separated by means of a knife. When the cloth has been removed from the openings of the flanges, where the hammer and butts are to stand, the flanges may be fastened again to their hammer butts.

If the flanges are without slits and only supplied with a hole for the centre pin, the old centre pins must be driven out sufficiently far with a fine aglet, that they may easily be grasped and extracted with a plyer. After removing the old cloth, cut a strip of bushing-cloth so wide that it fits exactly into the hole in the flange. At one end fasten the two sides a little way up with glue, and press the glued part. When the glue is dry, cut this end to a point, so that it may be used like a needle, with the aid of which the strip may be run into the centre pin holes. The other end of the strip must by very carefully supplied with a little thick glue, and when the flange has been drawn to the very edge of the strip, the remaining strip must be cut from the flange. To fasten the flanges to the hammer-butts, &c., one must be supplied with centre pins of No. 19, No. 20, and No. 21; try which of these numbers will fit snugly into the butt without splitting the wood when being driven in. Before making the connection between flange and butt, try whether the centre pin can turn readily in the lined hole. Should the hole be found too small, it may be enlarged by roughening a centre pin of the size chosen for pinning, by turning it in sandpaper; the thick end of the pin is grasped with a plyer, or, still better, it is clasped in a hand-vice, and, holding it by this handle, the roughened pin is moved about in the cloth-lined hole, whereby it acts as a file.

BUSHING THE KEYS.

In nearly all pianos requiring an amount of repairing, the cloth in the holes of the keys has been worn away so much by the constant friction with the key pins, that the keys, while being played, knock against each other. A quick way to remedy this is to drive little wooden blocks near the opening to both sides of the keys, thus diminishing the size of the apertures. This method, however, is reprehensible, because the work does not last. The proper way is to remove the old worn cloth, and to cut strips of bushing-cloth corresponding in width to the length of the opening. In order to glue these strips into the openings which are made for the reception of the key-front pins, a dozen wooden blocks of about 3 c.m. length are required. On the one end of each block a plug of 1, 2 c.m. length must be cut so that its two sides project 4 m.m. each. The plugs must be exactly as thick as the key-pins, because they must fill the opening of the keys into which they are driven with the cloth to be glued. The plugs are driven up to the shoulders into the opening, and the cloth strips are cut outside, at the shoulders. Before removing the block from the opening, hit it lightly with a hammer; this will press the cloth under the shoulders closely to the key. To glue cloth into the apertures in the keys which are for the balance-pins, simple blocks of the thickness of the pins are used, being pushed into the openings with the cloth.

IVORY SCRAPING AND POLISHING.

Ivory scraping requires especial practice in manipulating certain tools, but some will-power will soon give the learner the desired skill. Should the ivory be only yellow, and not too far worn hollow, the key must be tightly stretched in the bench and the ivory carefully scraped with a scraper till all the gloss has disappeared, for the slightest hollow hinders a clean polish, and, in those places where gloss shows itself on the ivory, a sufficient evenness of the surface has not yet been obtained. The scraper consists of a steel plate, whose narrow sides have been polished perfectly straight on a stone with oil. With the sharp edges of these sides the scraping is done. If the surface of the ivory is too uneven to do the work properly, with a scraper alone, the same must be made even by means of a plane. In planing, as well as in scraping, extreme care must be taken that the ivory shows no bumps; this will not be so easily accomplished by the novice, and therefore another method may be recommended which takes a little more time, but is productive of a good result. Paste sand-paper of No. 1 or 1½ on a wooden block, and herewith make the surface of the ivory even. The ivory will not take a polish directly on the surface as left by the use of the sand-paper, but it must be rubbed so long with the finest sand-paper, No. 00, until every trace of the scratches left by the coarser paper has disappeared. The polishing of ivory is done by means of a wooden block, of about 11 c.m. length, 8 c.m. width, and 6 c.m. height. The under surface of this block is covered with 8 m.m. thick grey rubbing-cloth, or felt, and this is again covered with action-leather, which is nailed to the sides of the block. The material for polishing is pulverized chalk, which is spread on the leather, and well moistened with alcohol. The chalk is to be spread on the leather by the fingers, and all grit must be removed. The block is then rubbed with a round movement over the ivory, until the polish is satisfactory. The leather must be kept moist during the process, and at every moistening chalk must be added. With insufficient moisture the chalk sticks to the ivory and must then be removed by means of alcohol. After polishing, the streaks from the chalk are also removed by pure alcohol.

REPAIRING KEYS WITH IVORY.

The ivory covering the keys consists of three pieces; namely, the front piece, the head-piece, and the tail-piece. The quality of ivory is distinguished by numbers; thus, No. 0, No. 1, No. 2, No. 3, No. 4. The lowest number indicates the best quality. The colour of ivory is assorted for every set of keys and, in repairing keys, the ivory used must match that on the keys perfectly. Should the ivory on keys be too worn, the best and, no doubt, the cheapest remedy is to pack them, and send them to a key-factory to be covered. Do not, however, fail to remove that ivory from the keys which is still in a good condition, because this ivory, yellow from age, is a valuable material for repairing old keys, and is more expensive than new ivory, when purchased of a supply-house. Celluloid, for covering keys, is obtainable in sheets of 7⅛ octaves, and for key fronts in strips.

If a piece of ivory is to be removed in order to glue another in its place, a hot iron is held to it; or, if one wishes to protect the ivory against scorching, a hot brown-stone held against it for a while will suffice to enable a removal of the ivory from the key with a knife blade.

If a head-piece is to be glued, the edge which must fit closely to the tail-piece must be joined with a plane. After glue has been applied to the wooden part of the key, lay the ivory head-piece upon it, put a wooden block before the fore-edge which projects somewhat beyond the front of the key, and then screw the head-piece closely to the tail-piece in a workbench. A block of hard wood, whose outer edges have the exact measurements of the head-piece, is well heated, and, with the aid of a hand-screw or a steel spring, this warm block presses the head-piece to the glue-spread surface of the key. If a tail-piece is to be replaced, drive a round iron beside the tail-piece, at its back, into the key; with the aid of this arrangement the tail-piece may be pressed closely to the head-piece. The joint between the head-piece and the tail-piece cannot be close enough, for, after polishing, the slightest opening will show the joint as a dark line. Care should be taken that no glue remains in the joint of the ivory pieces, because it also makes the joints specially visible.

REGULATING THE ACTION.

Before the keys are placed in their frame, ascertain that the frame fits perfectly where it is to come in contact with the bottom or key-board, so that a hitting together of these parts may be avoided. The very slightest space between these two parts may be the source of a very disagreeable disturbance during a performance on the instrument. Whether the parts of the key-frame fit closely on the key-board or not, is to be tested by knocking on them. See also if the key-frame and the action may be easily moved into and out of the piano-case; if not, plane and file must be employed to remedy the trouble· The under part of the key-frame, also the side parts of the action, as well as the key-board, may be smoothed with powdered soap-stone, and then rubbed over carefully with a cloth. After this has all been properly arranged, the piano-hammers must be brought into proper position to their strings, and hereby the screws on the hammer-butt flanges must be tightly fastened. Observe carefully that the hammers do not hinder each other's movements. Sometimes the removal of the keys from the frame is not without difficulties; the back-check of the first key beside each action-bracket must be brought down so that, with a little precaution, these keys may easily be removed from the frame. The openings thus left afford space for the removal of the other keys. In replacing the keys, the one taken out last should be put back first. When the keys have been replaced, try each one separately, to make sure that it moves easily on its pins; wherever this is not the case, the bushing-cloth in the openings of the keys should be pressed together with a key-plyer. Furthermore, care should be taken that the jacks stand in their right places under the hammer-butt knuckles. Should a jack stand aside from the middle of the hammer-butt, sufficient paper to put the jack in its proper position must be placed on the side to which it inclines, under the rocker, to which the jack is fastened by means of the centre pin. The regulation of the action continues:—The jacks are to be fastened under the hammer-butt knuckles by means of the screws on the rocker, in such a manner that no perceptible space remains between jack and knuckle; nevertheless, the jacks must go easily under the knuckles at the falling back of the keys. To ascertain that this is the case with all jacks, a test may be made while the action is in the piano-case. Every key is struck separately, the finger being allowed to remain on the key after the stroke. Raise the finger carefully, but do not lift it from the key until the latter has reached its resting position; a renewed stroke will then prove whether the jack has taken its position under the knuckle properly, or whether it stands too high. Every key which has prevented the hammer from striking the strings, *i.e.*, where the jack stands too high, must be marked by a perpendicular line; a horizontal line may be drawn on those keys which, on being lightly touched, reveal a perceptible space between the jack and the hammer-butt knuckle; the length of the marks may be proportioned to the greatness of the faults. Having thus examined all the keys in succession, the faults must be remedied outside of the piano, by means of the screws in the rocker. This process must be repeated until every jack works properly.

The keys must in most cases be levelled outside the instrument; in order to make this possible, the key-frame must first be screwed in place, and, after having arranged the two end keys for the depth of the touch, place two more keys under a straight-wood, in a straight line with the two end keys, and so as to form three nearly equal spaces between the four keys. Taking the action from the instrument, and placing it on a level surface, the four keys before placed being in exact line under the straight-wood, the other keys may be levelled. The keys must be inspected when they are in the piano. Looking from one end of the row of keys over the same, a few changes will be found necessary. Balance-rail cloth punches are obtainable in thicknesses of 4 m.m., 3 m.m., and 2 m.m.; paper punches, for levelling the keys, are made in thicknesses grading from 2 m.m. to the thinnest tissue paper. Front-rail punches in green and white cloth are obtainable in thicknesses of 7 m.m., 5 m.m., and 4 m.m.; front-rail paper punches for regulating the touch are also to be had in various thicknesses. A pincette or a tweezer is used for placing or removing the punches under the keys. After the keys have been levelled, see that the spaces between them are equally great. The spaces are regulated by bending the front pins in the key-frame sidewise, with a key-spacer. In carefully pressing down a key, the hammer should fall back to about 3 m.m. space between hammer and strings. The falling back of a hammer occours at the moment when the jack severs its connection with the hammer butt. When a key is pressed down the screw affects the tail of the jack, driving the jack from under the hammer-butt knuckles. These regulating-screws are easily found, even if they are not in their usual places, because they always perform the same service. The tool used to regulate these screws is a regulating-screw driver, specially manufactured for the purpose. Regulating the distance to which the hammers rise is troublesome work, and requires much time, for when the action is in the piano one cannot get at the regulating screw for the jack, and thus the work is connected with a continual taking out and replacing of the action. Therefore only a few hammers should be regulated in this manner, and these may then serve as a guide for those which are to be regulated outside the piano. Regulating the hammers outside the piano is most accurately done by placing the action on a straight surface, *i.e*, on a work-bench, &c. A wooden strip, having the curve of the hammer line, serves with its lower straight surface as level. This strip, which represents the strings, is now placed so high that the hammers which were regulated in the piano just touch it when the keys are carefully pressed down; the other hammers are also made to touch this strip. For frequent use it is advisable to make an arrangement which may be set; for instance, a strong rail, fastened by two feet and supplied with screws, by which the wooden strip for the rising distance of the hammers may be raised or lowered.

Much practice is needed to give a good touch to the action. As his fingers touch the keys, a good regulator feels how the touch should be. For those not skilled in laying the touch, the following directions will prove helpful. Take a paper-punching of 1 m.m. thickness and lay it on top of the front-rail cloth-punching, directly under the key. Put so many paper-punchings, according to the requirement of greater or lesser thickness, under the cloth-punching, that the hammer will just fall back when the key is pressed firmly. If the paper-punching which lies on top of the cloth-punching, and serves merely as a tool, is now removed, the proper depth to which the key must descend will have been obtained. This process should be applied to all keys, after which the keys must be examined in pairs as to the exact equality of their descent. For this purpose stroke across the surface of each pair of keys with the fore-finger, but so lightly that their position remains unchanged; the slightest projection of a key is then perceptible. This same unevenness (if it existed) must also be felt when both keys have been brought down under equal pressure to their cloth-punchings, or else it must be made by adding or removing cloth-punchings. Unfortunately, this test cannot be applied to the so-called sharp keys. After the keys have been regulated for the touch, the back-checks must be directed for the hammer-butt heads, and set to catch the hammers precisely, and so that they do not fall too deep into the back checks. The regulating of the action is now completed up to the work for a good and precise damping of the strings.

Before the dampers are placed in the piano through fastening of the damper-rail, loosen the damper-felt with a felt-picker. After the damper-rails have been-adjusted in the piano, direct the damper-heads by means of their lever, exactly upon the respective strings. Take care that the damper-felt does not dampen strange strings by touching those of neighbouring tones.

When the dampers are set and the screws on the flanges of the damper-lever tightly drawn, examine, by striking the hammer, if each damper works properly. Should single strings be found which are not sufficiently damped, the cause may be sought in the damper felt, but if a series of strings is affected, the damper-lever, in connection with the damper-rail, up to the trap-work must be examined. When the damper-rail is being lifted, all the levers should move precisely and equally just after it is set in motion. Should a lever move too slowly, place strips of paper under that part of the same which comes in contact with the rail; precipitance on the part of a lever when the rail is being lifted must be remedied by filing the wood at the respective place. As the position of the repairer is at the back of the piano during this work, it is more convenient to move the damper-rail with the hand than with the pedal. Besides, in this way the movements of the damper-levers can be better observed. It is not advisable to insert the damper-lifters before the dampers are entirely arranged and the strings perfectly damped by the damper-heads. The action should previously be removed from the piano, for in case the lifter-wires are too long the distance between the lifter-buttons and the damper-lever can thus be better regulated. Regulate this distance with the lifter-button, so that there is a space of 2 m.m. between the last treble damper-lever and the lifter-button, and a space of 6 m.m. between the first bass damper-lever and the lifter-button. These measurements must grade evenly in the space between bass and treble. In replacing the action, make a space of 2 m.m. between every key and the lifter-wire; to regulate this, press every key with the utmost care, and, while feeling with the lifter, one can readily perceive if there is too much or too little space. If any lifter-wires are too long, they may quickly be shortened with cutting nipper and file; however, if they are too short, the punchings of the respective keys must be heightened. If the lifter-wires have worn deep holes into the punchings, remove the latter from the keys and if they are not to be replaced by new punchings, glue them again to the keys, changing the position so that the lifter-wires stand beside the holes.

TRAP WORK.

Everyone who examines a pedal action will soon be well acquaïnted with it; therefore a description of its use and arrangement is superfluous. Much, however, is done with the trap-work which deserves censure. Especially the tuners like to hurry over the work with the untidy and sometimes rather uncomfortably-placed pedal-action. In order to stop the squeaking of the pedal feet, or of the trap-work, or its springs &c., they partly smear these parts with soap and oil, which, afterwards, combined with dust and sand, form a sticky mass which is again helped with petroleum, which renews and increases the squeaking and whizzing noises. Most certainly the above is not true of all tuners, for as well as there are owners of pianos who take care of their instruments, there are also conscientious tuners who strive to keep the piano entrusted to them in good order. To remedy the above-mentioned conditions, the woodwork must be cleaned with a scraper, pins and pedal wires with fine sand-paper until everything looks like new, and all leather and cloth parts must be renewed. Put black-lead, pulverized and mixed with tallow till it forms a stiff pulp, under the springs. If the pedal feet have become loosened, fasten them again. Special attention must be paid to the lyre; the same must fit with its pins closely into the lyre-block; the latter must also be securely fastened under the key-board. The lyre support-stick must give the lyre an immovable support. After all this repairing the piano should be tuned, and as one has then to strike each key separately, defects which may have remained even with the most careful work, may then be discovered and remedied.

TONE REGULATING.

When the piano is in good tune, test the entire work by playing upon the instrument with and without the use of the pedal. Going from note to note, strike each key hard and gently, and if it is found that the sound is pleasant with the light stroke of the hammer, but harsh with a stronger stroke, the crown of the hammer-head which comes in contact with the strings must be spared in felt picking, and one must stick from the hammer-head crown deep into the felt with two or three needles of No. 2 or 3 in the picker. If, however, the sound comes hard and thin, the felt must be well picked on the crown of the hammer-heads with four needles of No. 4 in the picker, which must be held in a direction 45 degs. from the perpendicular line. If the hammer-heads are new, the outer crust of the felt on the crown of the hammer-heads must be removed with a sand-paper file. The work for the refinement of the sound character is called *tone* regulating; the word *sound* regulating would be better, for the tuner regulates the tones with the tuning-hammer by means of the tuning-pins on the strings, and through the vibratory proportions of the strings, whereas the tone regulator (or, more correctly, the sound regulator) regulates on the hammer-heads the colour of the tones. This work also requires a vast amount of practice and experience.

REPAIRING ON UPRIGHT PIANOS.

Before one can begin to work at the instrument the same must be thoroughly cleaned. Beside removing separate parts of the casework, such as top frame, bottom frame, fall-board, core, key-slip, &c., the action and keys must also be taken out, and if, in repairing the sounding-board or its bridges, the key-bottom is in the way, the same may readily be taken out after the trusses have been removed. After cleaning the piano, all parts of the sounding-board and the wrest-plank must be examined and repairs must be made according to foregoing instructions. Also the pedal action or the trap-work must be put in perfect order; then examine separately the action parts, and, taking the well-preserved parts as models, repair wherever it is found necessary. Try every screw, and see that every part is securely in its place. Hereby the spaces between the various parts may be ordered and care taken that similar parts of the action are in parallel position, and if a part deviates from the proper position, put paper strips on the respective side under the flange to which the member is fastened. If the damper-rod, which lifts the dampers from the strings when the forte pedal is being used, is rusty, take it out. With a little care this may be done without removing the damper-levers. Scrape the damper-rod with fine sand-paper and smooth it with black-lead mixed with tallow; in order that the damper-levers may not be soiled with the mixture, rub off the damper-rod very thoroughly with a piece of leather before it is put in its place. If the springs on the damper-lever squeak, rub under every spring with a leather on which there is a little black-lead. After the action has been well examined and repaired the felt on the hammer-heads scraped with a sand-paper file, the crown of the hamer-heads picked with a felt-picker, and the damper-felt loosened with needles, the action may be replaced; see that it is securely fastened in its brackets. If the felt on the hammer-heads is so worn that it must be renewed, it is best and cheapest to order new hammers, and place them instead of the old ones. For this purpose take the end hammers from the different sections of the action, and send them as models for the new hammers to a supply-house. These models must be numerated as they stand in the action, and so that No. 1 begins with the first bass hammers. For boring the new hammer-shanks, leave the hammer-shanks on the model hammers. To remove the old hammers from the hammer-shanks, hold a very hot iron to each hammer-head—in this wise the glue is burned loose from the hammer-shank; after this has been done, the hammer-head may be removed from the shank by moving the latter back and forth in the former. Before gluing the new hammers, the old glue has to be removed from the shank by means of a toothing-iron. If the shanks go through the hammer-heads as in the grand piano, the shank must be driven from above out of the hammer head, by means of an ironpin, which just fits into the hole in the hammer-head. Of course the hammer-head must have a firm support during this process. For this purpose, cut a groove in a piece of hard wood large enough to hold the curve of the hammer-shank, and so that the hammer-head rests securely on the hard wood.

If the hammer-rail moves in hooks and does not rest properly on all action brackets, try to make it fit by bending the hooks. See that the distance between the hammers and the strings is 4·8 c.m. In European pianos the hammer-rail is frequently to be found tightly screwed into the wooden action post. With this arrangement the piano pedal is then connected, with a shifting of the rail to which the hammer-butt flanges are fastened, and the shifting of the rail so arranged that in using the piano pedal the hammer touches, for instance, only two strings instead of three, and there where there are only two strings for each note, the hammer stroke is confined to but one string. Another arrangement for the use of the piano pedal has the hammer-rail consisting, so to say, of a double rail. The first rail is tightly screwed to the action bracket, so that it is immovable, while the second rail is connected with the first by means of flanges, and is used as a movable member to bring the hammers closer to the strings.

If the hammer-shanks are out of shape, so that the hammer-heads are not parallel with their neighbours, remove the worst shanks and replace them by new ones; those shanks which are not so badly bent may be treated as follows: Bend the hammer-head side-wise into the correct position, or a little beyond, and grasp the hammer-shank with a moderately-heated hammer-shank plyer, and hold it thus for a while. This usually has the desired effect.

If the hammers move sluggishly backward or come to a standstill near the strings, a dampening of the outside of the bushing-cloth with alcohol, &c., will remedy the fault for a short time; the proper way, however, is to remove the centre pins and to put new ones in their places. The way in which to place new centre-pins and the cleaning, respectively enlarging of the bushing-cloth holes with a roughened centre-pin or centre-wire, has been explained sufficiently under the heading "Repairs on Square Pianos." The necessary work and the arrangement for the keys was there also described. In placing the keys, if the same are supplied with a key-rocker, direct them under the abstracts, and screw the key-rocker so high that the jack can easily fall under the hammer-butt knuckle without causing a perceptible space; the same passes for the capstan-screws, which take the place of the key-rocker, and also for the dowel-props, which not only take the place of the abstracts but also that of the key-rocker. In levelling the keys, the same directions must be followed as with the square piano, however, the work is much easier, because it may be done with the keys in their proper places in the piano-case. In setting the hammers before the strings, regulate as with the square piano, by means of regulating-screws, which affect the tails of the jacks. In many German pianos, the regulating-screw is directly in the jack or close beside it in the rail; in these arrangements the jacks are then without a tail. In upright pianos the disconnection of the hammer-butts and the jack is sufficient with 2 m.m. space between the hammers and the strings.

In most pianos provided with under-dampers is found a springrail; the springs fastened in this rail affect the hammer-butts for the falling back of the hammers. The springs, instead of being fastened to a rail may also as a matter of fact be fastened directly to the hammer-butts, being then hooked to cords which are fastened on the flanges, and may thus affect the retreat of the hammers. These arrangements are very serviceable in setting the hammers before the strings, which are regulated by means of the disconnection of the jacks and the hammer-butts; in this work the keys have to be pressed down very carefully, and thus it often happens when no springs or similar arrangements have been supplied for the retreat of the hammers, that the latter stick before the strings, making an exact regulation of the hammers' course up to 2 m.m. before the strings far more difficult. In setting the hammers, the bridle-ribbons which draw back the hammers by the butts, act too late to assist in the work, and if the hammers do not fall back precisely, help must be sought; for instance, by the weight of a saw-file placed on the stems of the back-stops during the work.

If the touch of the keys is to be regulated under the front railpunchings, follow exactly the directions given for the square piano. If, however, as is the case with many German upright pianos, the regulating of the touch is done at the back lever of the keys, a special stop-rail is required at the other end above the back lever of the keys, on which rail the movement of the keys is regulated for that which we call touch. This stop-rail must stand as far above the back lever of the keys as required for the touch of the keys or for the depth of the front lever's descent. If, with this arrangement, the touch of various keys is not deep enough, take away from the end of their back lever; on the contrary, if the touch is too deep, paper glued on the back lever of such keys will diminish the depth of their movement. The front rail punchings, which must not be wanting with this arrangement, are then a special surety for the durability of the keys and of the stop-rail during very hard playing.

Setting the back-checks to the back-stops, which is regulated by bending the back-check wires sidewise, is best done with a regulating-plyer, which tool is specially manufactured for this purpose. The wires of the back-checks possess a special stiffness, so that in trying to bend them with a common plyer one runs the risk of loosening them where they are fastened in the jack-rocker. This also occurs when one attempts to set the back-checks to the back-stops, back or forward, with the fingers; for bending in this direction use a regulating iron.

The catch of the back-stops in the back-checks must occur as soon as the hammers have made one-third of their back course from the strings to the hammer-rail. If the catch occurs when the hammers are nearer the strings, the touch loses elasticity, and may easily cause a blocking of the hammers; if, however, the catch of the back-stops occurs at too great a distance from the strings, the repetition is greatly harmed, since in upright pianos the repetition is dependent upon a proper catch of the back-stops in the back-checks.

If the soft or piano-pedal causes a shifting of the hammers, the bridle-tapes may be held so tensely by the bridle-wires that the jack may easily fall under the hammer-butt knuckles without leaving a marked space between both parts. The sooner that the bridles step into action with the hammer butts the more the back-course of the hammer is hastened, and thereby the repetition enhanced. But if the arrangement of the piano-pedal is so that the hammer-rail brings the hammers nearer to the strings, the bridle-wires are generally so placed that in the lifting of the hammers by the hammer-rail, the jack-rockers or the abstracts remain in direct connection with the keys; the bridle-tapes cannot be as tense as in the other case. Should bridle-tapes be defective, or missing in the action, do not glue the new ones on the stumps of the old tapes. Remove all old rests of tape and make a little cut with a saw, close under the back stops, into the hammer-butts, wherein the new bridle-tapes may be securely glued. For instance, if new bridle-tapes are glued upon the rests of old ones, they become so stiff that they do not answer the purpose and disturb the movements of the respective action parts.

In attending to the damping of the strings, see that the damper heads are directed exactly upon the strings intended for them. If the piano has under-dampers, touch the loud or forte-pedal with the foot and observe if all damper-heads leave the strings simultaneously, if not, use a damper-spacer on the damper-wires, so as to bring the dampers back or forward. Hereby see that the damper-felt lies full against the strings, otherwise it must be made to do so by a special bending of the wires. The dampers are not raised by the forte-pedal alone, but they are also separately lifted by the keys connected with them. The damper must not be so closely connected with the key that a touch upon the latter causes it to leave the strings; that should not occur until the key has moved a certain distance. The lifting of the dampers from the strings is done by the damper-spoons, which are fastened on the hind part of the jack-rockers. By a backward or a forward bend of these spoons, set the dampers so that in using the key the damper-felt stands 3 m.m. from the strings. In using the forte-pedal, however, the damper-felt should be separated 5 m.m. from the strings, for it is no pleasant sensation in the touch if in using this pedal the spoons knock against the damper-lever. The damper may influence the touch just as unpleasantly if the hammer-spring rail, which serves also as stop-rail for the dampers, is too far from the the damper-wires. For instance, in forcible playing, the damper is thrown farther from the strings than the damper-spoon is capable of bringing it. If there is no support for the damper, or if this support, the stop-rail, is too far from the damper-wire, which should come in contact with the stop-rail, a marked space may form between the damper-spoon and the damper-lever. This space, through a reaction of the spring on the damper, manifests itself as a thump upon the damper-spoon, and is thus imparted to the touch. After these explanations it is self-evident that the damper-wires must rest against the damper-stop while the forte-pedal is being used, so that the damper cannot be brought more than 5 m.m. from the strings. If the stop-rail is fastened on brackets which have been bent to obtain the above described order of the dampers, see whether the springs have remained in their proper place on the hammer butts, and, if not, this may easily be regulated by moving the hammer-spring rail (or damper-stop rail, as it is also called), according to the requirements, either higher or lower in the slits of the brackets.

If the piano to be repaired has upper dampers, the row of damper-levers which, with such dampers, lie horizontally instead of standing perpendicularly, must be brought into a straight line after the damper-heads have been directed upon the respective strings. This setting of the damper-levers is done according to the arrangement, either by bending or screwing the wires which connect the damper-heads with the damper-levers. Setting the wires so that the damper-heads are pushed nearer to the strings the damper-levers are lifted, but the latter sink if the work on the damper-wires operates in the opposite direction. It is hardly necessary to mention here that the damper levers must run parallel with each other, and that where this is not the case it may be effected by means of paper strips placed on either side under the damper-lever flanges. The damper-lifter wires, which are with upper dampers, are to be found in front of the action; they are tightly screwed with their upper end into moveable butts, connected with the damper-levers. Before putting the lifter-wires by their lower end into their place in the holes of the jack rockers they must be exactly directed or set to the middle of the jack rocker or to their holes in the same. The wires must then be screwed so high that 3 m.m. space remain between the damper-felt and the strings when the keys are pressed. To insure that the lengths of the lifter-wires are all properly ordered, tread the forte-pedal. Hereby the damper-heads are lifted from the strings, and all the lifter-wire buttons rest closely against the jack-rockers; from the position of the damper-levers which rest with their full weight on the lifter-wires, it will be perceived if one lifter-wire is longer than the others. By bringing the damper-levers into a straight line, which is done by screwing the lifter-wires into and out of the butts of the damper levers, the wire-lengths may be regulated.

After frequent practice in repairing these two kinds of pianos one will have become skilled in the various works, and will have obtained a certain understanding for the purpose of the different action parts, so that he may confidently begin to work upon a grand piano action.

REPAIRING ON GRAND PIANOS.

The separate parts of the instrument are screwed apart and cleaned according to the directions given for the square piano, and wherever it appears necessary separate parts may be renewed.

Special attention must be given to the fit of the key-frame with the key-board, for the key-frame of the grand piano cannot be screwed to the key-board on account of its shifting through the piano pedal, and therefore, a close and perfect fit of these parts to each other must be sought. It is especially the front-piece of the key-frame which, not fitting perfectly against the key-board, causes a noise when the piano is being played. In fitting the key-frame to the key-board the keys may be removed from the key-frame, to do which the latter must be taken out of the instrument; after having firmly screwed the action into its place again, the work for the fitting may be begun. To test the correctness of the work, tap on the various parts of the key-frame with the finger, and by no means forget to screw the key-blocks, which may influence the key-frame, in their places. Having finished the work for fitting the key-frame to the key-board, scrape all the adjoining parts of both with fine sand-paper, Nr. 0, in the direction in which the key-frame runs. The respective surfaces are then rubbed with powdered soap-stone and a leather until they are smooth. Hereafter every grain of the powder must be removed from the wooden surfaces, as loose powder may cause a grating noise when the key-frame is being shifted. After the frame is in order the iron square lever, which has to shift the key-frame, must be inspected as to its firmness in the pin, &c. The pedal-action must lay the iron square lever close to the key-frame, and that without causing a pressure. A noticeable space between frame and lever will cause a clattering noise when the piano pedal is being used. The spring which brings back the key-frame after the pedal has been used, must be strong enough to cause an energetic backward motion of the key-frame with the action. If the spring has become weak, a layer of card-board placed under it will bring it closer to the frame, thus giving it greater strength.

The hammer-heads have specially rounded tails for the catch in the back-checks, and these tails must be roughened by means of a tooth-iron, or of very coarse sand-paper, because the escapement-lever springs make the catch in the back-checks more difficult. The roughening should not be done lengthwise, but across the hammer. Then set the hammers to the strings, and if hammer-heads are found out of the proper position remove the hammer-shanks and glue the hammer-heads in a straight direction again. If the movement of a hammer is not in a direction parallel to that of its two neighbours this must be rectified by placing paper strips under the hammer-butt flanges. The jacks must stand exactly in the middle of the breadth of the long grooves of the escapement-levers, and these levers must be directly under the hammer-shank knuckles. The escapement levers can be set on the jack-rocker flanges. If the jacks rub the wood in the openings of the escapement-lever remedy the fault by placing a round-pointed wire under the centre-pin on that side of the jack where the friction occurs, very near the bushing-cloth, and then serve the wire a slight blow, which drives it into the wood. Hereby the centre-pin is driven over, and thereby the jack comes to stand in the middle of the breadth of the groove in the escapement-lever. However, should the driving over of the centre-pin not be sufficient after this the experiment may be made on the other side of the jack, and here above the centre-pin. The jacks must reach exactly the middle of the hammer-shank knuckles, and any deviation of the jacks from this line must be corrected or regulated at the jack-cushions. Thus, if a jack ought to stand further forward, push a little strip of stiff paper into the cushion-felt; remove a little of the felt if the jack is to be brought farther back. The height of the jacks must be so arranged at the regulating-screw in the escapement-levers that they stand the thickness of a piece of paper lower at the upper edge of the escapement lever. However, if the jacks are lower in the escapement-lever, the position of the hammers becomes insecure, that is, one cannot order the hammers which should stand in a straight line, for, according to the strength of the stroke upon the key, the hammer will stand higher or lower. If the polish of the black-lead on the rims of the escapement-lever, where this stands in connection with the knuckle, is worn, it must be renewed. The way to apply and polish black-lead has already been described in dealing with the repairs on bridges in square pianos.

If the leather of the hammer-knuckles is worn, or if the knuckles have been beaten flat by use, and have lost their original curve, remove the old leather and replace it by new leather. For this purpose choose firm, elastic, but not hard, action-leather; cut strips of it wide enough to cover the knuckles well; choose also an appropriate thickness of the leather. One end of the prepared leather strip is to be glued firmly into the edge between the hammer-shank and the knuckle. This work should be taken up groupwise. When the glue applied to the first hammer is firm enough, apply glue to the edge of the knuckle; place the leather strip over the knuckle, and hold it closely drawn over the hammer-shank. With the strip held in this position, take a simple cutting-nipper and press the leather into the corner or edge of the knuckle with it. By means of this process the leather strip lies in a good curve, and with sufficient firmness around the knuckle, and may be cut with a sharp knife at the edges of the knuckle; the remnant of leather may be used for farther knuckle-covering. Having mended all action parts, begin to regulate the action.

The hammer-shanks must not rest on the cushion, as they do in the square and in the upright pianos, but must be suspended at 4 m.m. distance from it. Under frequent testing by moving the keys, the hammer-heads are to be set in an exactly corresponding height, or in a horizontal line. The work is done at the capstan-screws, or, if the action has key-rockers and abstracts, on the screws of the key-rockers; for the last-named screw there is manufactured a double-head screwdriver, which tool facilitates the regulating of the screw.

Levelling the keys must be done outside of the piano, and is exceedingly troublesome when the keys and action are joined by abstracts for every time that paper-punchings or packings are laid under the balance-rail the respective abstracts must be lifted from the centre-pins of the key-rocker and then replaced. With some keys the abstracts cannot be lifted from the balance-rail pins without lifting the action from the keys, whereby the underlaying of paper-punchings is necessarily made more difficult. In the factory the keys are levelled in the following manner:—A piece of lead, heavy enough to substitute the weight of the respective action part, is nailed to the back lever of every key. The key-frame, with its keys, is then fastened with the key-block to its place in the piano without the action, and the keys may then be levelled. Having removed the leaden weights and screwed the action into its place, slight changes will be found necessary here and there.

If a key should stand just slightly higher than the rest place a wooden block directly on the key-button over the balance-pins, whose projection over the key will be received or taken up by a hole in the block; a gentle blow of the hammer will then bring the key lower on the balance-rail. However, should a key and its fore-lever be lower than the neighbouring keys, this may be changed by using a sand-paper file at the proper place on the back lever where the key rests on the key-cloth; hereby the time and the work of screwing the action from the key-frame or for loosening the abstracts from the key-rockers is saved. The most convenient arrangement for the levelling of the keys is where the jack-rockers are lifted by means of capstan-screws instead of by abstracts; the former are screwed directly into the keys. Mostly all American and European pianos contain this arrangement.

The relapse of the hammer occurs according to the well-known method, through the regulating-screw, which affects the tails of the jacks and sends them from under the hammer-shank knuckles. The relapse of the hammer has here also to occur 3 m.m. from the strings.

When released from the back-check the hammer should not alone be carried by the repeating-springs of the escapement-lever, but should also be gently lifted; consider well that a tardy lifting of the hammer through the repeating-springs, will make the repetition of the hammers heavier; and, again, that if the lifting occurs with a jerk a sure catch of the hammers in the back-checks may not be counted upon. If the repeating-springs lie under the escapement-lever the regulating of the springs is best done by means of two wires, each supplied with a little hook. For instance, to weaken a spring hold it with one hook at the escapement-lever while the other draws it downward; to strengthen a weakened spring draw it upwards with one hook. Test whether the escapement-levers can come low enough not to disturb the catch of the hammers; the regulating is done on the regulating-wire hooks for escapement-levers, and these hooks must be screwed, so that if, for instance, a hammer is held by the back-check, a little space must still exist between the hook and the escapement-lever.

The descent of the keys for the touch is, as has before been said, 10 m.m. for the first bass key, and 9 m.m. for the last treble key. On account of the repetion, the catch of the hammers in the back-checks is to occur as high under the strings as is practicable; thus, the movement of the hammers till under the strings is reckoned to be 4·8 c.m., at most, 5 c.m., and the relapse of the hammers into their back-checks should be 1·8 c.m., reckoning from the strings. Special care must be given to the slanting position of the back-checks, so that with an energetic relapse of the hammers from the strings the hammers cannot slip past, in front of the back-checks. Most certainly, the more slanting the back-checks are placed the more difficultly are the hammers caught by them, but if the hammers slip down on the back-checks, not only the capability of repetition in the action is lost, but the touch of the piano becomes such that it may well be called miserable. A test to insure that this evil cannot arise may be made on the action, outside of the instrument:—Strike each hammer into the back-checks by means of the keys, thereby allowing one hand to take the place of the strings over the hammers, and hold the key on its front-rail punching; then try whether it is possible to bring the hammer past the back-checks by means of the hand. One cannot be too conscientious in this work, because pianists often drive the hammers past back-checks slanted so that such a thing seems almost incredible.

In the hammer-shank flanges there is a regulating-screw for a certain height of ascent for the escapement-lever. Of course the escapement-lever, aided by the escapement-lever spring, must not drive the hammer up to the strings when the hammer has been released by the back-checks, for if the hammer should reach the strings this would produce a tone against the player's will; therefore the regulating-screw is to be so placed that it stops the escapement-lever in its ascent as soon as the hammer-head is within 4 m.m. of the strings. The hammers of the grand piano are not lifted at first by the jacks, as, for instance, in a square piano, but rather by the escapement-levers, while the jacks do not operate until the regulating-screws detain the escapement-levers. As the escapement-levers lift the hammers within 6 m.m. of the strings, and the hammers relapse from within 3 m.m. of the strings, the jacks lift the hammer-heads just 3 m.m.; this must be considered when regulating the height of ascent of the escapement-levers outside of the piano.

The regulating and setting of the dampers may be taken up as one of the last works, and although this is considered a peculiar and difficult task, there is little to explain, everything seeming too self-evident. One can explain to no one that if a damper-head stands or lies so, or so, that the damper-wire must be bent thus, or thus; or that this and that must be done to the wire, or to the damper-head, or to the damper-lever; these are things which must be recognized while at work, and then they depend upon the skill of the hand. Following are a few guides for work on the dampers :— Set the damper-heads on the damper-lifter wires so to their strings that each string is well damped. The damper-heads are to stand in a direction parallel to each other, whereby the spaces between them are to be equal. The row of damper-heads must be set so that the mouldings of the heads together have the appearance of the entire piece from which they were separately cut, and must keep this appearance when lifted by the forte-pedal. Every damper-wire must be able to move comfortably up or downward in its hole in the damper-guide rail, but not so loosely set that the damper-heads shake; not alone that shaky damper-heads look bad, but one runs the risk of having them knock together during energetic playing. If the material in the holes is worn the dampers and the lifter-wires must be removed, the damper-wire guide-rail be unscrewed and taken from under the strings, then the old bushingcloth must be removed and new cloth be put in its stead. With the base damper-wedges observe that they fall between the strings *directly*, and not by means of an unsteady side movement. The damper-levers must not rest on the keys, but ample space must be left between key-cloth and damper-lever. The damper-levers also stand free from the damper lifter-rail of the forte-pedal, for only thus can the damper-levers, with their lead, effect the damping of the strings. The damper-lifter wires are to be screwed so deep into the damper-lifter wire-flanges, which are fastened to the damper-levers by means of centre-pins, that when the dampers are lifted by the keys, the dampers in the base stand 6 m.m., and those in treble 5 m.m. from the strings. When the forte-pedal is being used, the damper-lifter rail has to move the damper-heads 8 m.m. from the strings, and to this height the damper stop-slot is to be screwed over the damper-levers in the piano. Farther works on the grand piano are to be done according to the directions given in the various chapters on repairs.

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