account from Mendel and Reissmann's Dictionary (1880, Art. *Flöte.*) may be cited. "In a dolmen in Poitiers there was found a flute made of stag's horn. . . . . This is a transverse flute, and the mouth-hole is perfectly made. The finger-holes, three in number, are in the upper part of the instrument and equidistant." This description is said to be taken from Fétis's *Histoire Générale de la Musique* (1869), but the original account refers to a totally different kind of instrument which is clearly figured and described, and which closely resembles the modern *ocarina*, being, in fact, a whistle.

Another instrument, described and figured by Fétis as a "*flûte*" from Otaheite, has in the engraving the appearance of a transverse flute, but seems, from the account of the manner in which it was sounded, to have been nothing of the kind. "This instrument," says the author, "was played nearly in the same manner as the transverse flute, except that the musician, instead of making use of his mouth, blew into the instrument through one of his nostrils, whilst he stopped up the other with his thumb." This flute must therefore have been also a whistle of some kind, for the impossibility of producing musical sound by blowing through the nostril across the lateral mouth-hole of a transverse flute, is manifest. I am informed that instruments blown through the nose are still common in some barbarous countries.

307. There being no reasonable basis for the assumption that the flute of our time is of really ancient origin, a recapitulation of the innumerable anecdotes concerning the αὐληταὶ, the *tibicines* and the *fistulatores*, would, however interesting, be out of place in this book, but as an old professor of the flute, perhaps somewhat strongly impressed with the virtues of a certain system of teaching, I may be pardoned for inserting here an expression of Xenophon concerning the teaching of Socrates, which I translate as follows: "For what flute-player, or what harp-player, or what other teacher, having produced competent pupils, is blamed for their degeneracy, if they, after having gone to other masters, should become less skilful?'—*Xen. Mem. I. ii.* 27.

CHAPTER XI.

ON THE FLUTE-TUBE AND ITS VARIOUS DETAILS AND ACCESSORIES, INCLUDING AN ACCOUNT OF THE QUALITIES NECESSARY FOR IDEAL PERFECTION.

§308. INTRODUCTORY.—310. DIFFERENT SIZES OF FLUTES.—311. THE MATERIALS USED FOR THE TUBES OF FLUTES.—312. *BOX-WOOD.*—313. *JAMAICA COCUS-WOOD.*—314. *EBONY.*—315. *CUBAN AND SOUTH AMERICAN COCUS.*—316. *OTHER WOODS.*—317. *IVORY.*—318. *METAL-LINED HEAD-JOINTS.*—319. *GLASS AND PORCELAIN.*—320. *METAL.*—321. *EBONITE.*—322. THICKNESS OF THE TUBE.—323. THE JOINTS OF THE FLUTE.—325. CONTRIVANCES FOR ALTERING THE PITCH OF A FLUTE.—326. *EXTRA MIDDLE JOINTS.*—327. *THE TUNING SLIDE.*—328. THE CORK, OR STOPPER.—329. *ITS MATERIAL AND CONSTRUCTION.*—331. *ITS POSITION.*—333. THE MOUTH-HOLE.—338. THE BORE. *ITS VARIOUS FORMS.*—342. *ITS DIMENSIONS.*—343. THE FINGER-HOLES.—345. *THEIR DIAMETER.*—347. *VEILED NOTES.*—348. *POSITIONS OF THE FINGER-HOLES.*—357. *VENT-HOLES.*—360. *THE c''♯ HOLE.*—363. *THE LATEST IMPROVEMENT IN THE c''♯ HOLE.*—364. *THE TENDENCY OF VENT-HOLES TO CAUSE UNDUE SHARPNESS.*—365. *THE SUPERNUMERARY d'' AND d''♯ HOLES.*

308. Introductory. The ensuing account of the tube of the flute, with its numerous accessories, and of the requirements of ideal perfection, is partly intended to enable the reader to understand the history of the flute, which forms the subject of chapters XIII. to XV., and to appreciate the defective construction of the earlier flutes, as well as the various modifications which the tube and its perforations have undergone during the last three centuries and a half of the existence of the instrument.

The only kind of flutes that we shall henceforth have to consider, is that formerly known as the Swiss, or German flute, transverse flute, *flûte traversière*, *flauto traverso*, *Schweitzerpfeiff*, *Zwerchpfeiff* or *Querflöte*; but at the present time generally called simply the flute, *flûte*, *flauto* or *Flöte*. A sufficient definition of this famous instrument is given in §87.

309. The finger-holes of the flute have at different periods varied in number from six to twenty-one: they are opened successively, though not always in regular order, to produce an octave (more or less) of the scale. The note generally regarded as the fundamental sound of the instrument is *d′*, and when all the fingers are removed, the note given is *c″*♯, except in the case of a recent invention which is particularly described in chapter XV.

The first, or lowest, octave is composed entirely of fundamentals. The second octave consists of the harmonics of the first, and is fingered in the same manner, excepting that the *d″*, called the middle *d*, generally has the *c″*♯ hole opened as a vent-hole.

Full details of the finger-holes and their uses, as well as of the theory and practice of the fingering of the third octave, will be found in subsequent pages.

310. Different Sizes of Flutes. Flutes have long been made of widely differing dimensions. That called the "concert-flute," which is the ordinary size, gives the sounds as they are written: its present compass may be fairly stated to extend three octaves upwards from *c′*, though the concert-flute can be made to produce unpleasant notes as high as *e″″*, and keys have sometimes been added so as to extend its downward limit as far as the *g* of the violin, or even lower. Some so-called bass flutes have descended a full octave below the concert-flute. Flutes have also been made of various sizes between those of the bass and the concert-flutes.

It may be necessary to explain here, that the *original* lowest note of the flute was always called and written *d′*, whatever its actual sound might have been, consequently a flute that really gives *d′*, when that note is fingered, is called a *d* flute, or is said to "stand in *d*"; a flute that gives *a* when *d′* is fingered, is called an *a bass*, or more correctly, an *alto* flute. An instrument, once popular, but now rarely used, called the *flûte d'amour*, sounds a minor *third* below the concert-flute.

The octave-flute, *d* piccolo, *petite-flûte*, *ottavino* or *flauto-piccolo*, gives sounds an octave higher than those written and fingered. Flutes of sizes between those of the octave and concert-flutes are called *e*♭, *f*, *b*♭, or *c* flutes according to the real sounds of the suppositious *d*; those above the octave-flute are called *e*♭, *f*, or *g* piccolos. For orchestral and solo performances concert and octave-flutes are now generally used; though the *f* flute has not yet received its final *congé*. As this instrument sounds a minor *third* above the concert-flute, it is often called the "third-flute." The flute *obbligato* to Bishop's celebrated song, "*Lo! here the gentle lark*," was originally written for the *f* flute, and an extremely effective part is assigned to this instrument in Spohr's immortal symphony, "*The Power of Sound*." Both these parts, however, I have always played on the concert-flute. Flutes and piccolos of the smaller sizes, especially those in *e*♭, are still much used in military bands.

Messrs. Rudall, Carte and Co. now manufacture an alto flute in *a*, an instrument of extraordinary power, of which an engraving and a description will be found in §687.

Excepting when special allusion is made to dimensions, almost all that is said in this book concerning the flute will apply to flutes of all sizes. The interest attaching to the smaller kinds of flutes being very limited, I have not thought it worth while to enter into minute particulars concerning them.

311. The Materials used for the Construction of the Tubes of Flutes. In giving so prominent a position to the subject of materials, I am not in the least degree seeking to subvert the broad principles laid down in chapters III. and IV., but I wish to emphasize the fact, already cited in chapter VII., that the question of the materials of wind-instruments, especially of flutes, is not of such an unimportant nature as some recent writers have tried to induce us to believe. Moreover, apart from the question of the influence of the tube of a flute on the pitch, power and quality of its sounds, it is obvious that the nature of the material of which it is made, is a matter of the gravest importance for other reasons. The chief desiderata, as far as the effects of material are concerned, are here enumerated.

The first necessity for a flute, as for most other desirable things, is that it shall be capable of enduring for a reasonable time.

The second consideration is that it shall retain its original calibre in spite of any adverse influences to which it may be subjected.

The third essential is that the nature of the material employed shall be such as to give rise to no cause for deterioration of intonation or quality of tone on account of age or use, but that it shall rather tend to promote changes calculated to improve original good qualities and remove or ameliorate any slight original defects.

The fourth point of excellence is that the tube shall not sympathise too readily with the aerial vibrations, but that it shall possess sufficient resisting power to retain the enclosed column of air in its proper shape and dimensions during any strain to which the tube is likely to be subjected, yet that the latter shall not be of such rigidity as to cause unnecessary expenditure of breath, or to deaden the sound-vibrations to an injurious extent; in fact, that it shall be:

"Something between a hindrance and a help."

The fifth item in the list of ideal perfections, is that the material shall be a bad conductor of heat, so that the pitch of the instrument may be preserved, as far as possible, during any change of temperature to which it is liable to be exposed.

The sixth, the least important, desirable quality is an agreeable appearance, and this should be capable of being maintained without the necessity for an irksome amount of attention.

We may now proceed to the particular consideration of the properties of the various materials that have been, and are, employed for the construction of the tubes of flutes.

312. *Box-wood* was one of the materials first used for this purpose, and it is mentioned by Mersenne (1637) as being more frequently employed than any other wood. It has many excellent qualities and some very bad ones. The tone of a box-wood flute is not to be surpassed in sweetness, but no reliance whatever can be placed on this material, as it absorbs moisture so readily that the bore of any wind-instrument made of it, is liable to continual change in its dimensions. Cornelius Ward (1844), formerly an eminent London flute-maker and a good authority on the subject, said that it was more fitted for the construction of a hygrometer than of a wind-instrument. When I was a child, I used to get over this difficulty by immersing my little flute in a tub of water before playing on it.

Box-wood, particularly that of Turkey, has an agreeable appearance, and bears a good natural polish, but, on account of the above mentioned defect, it has long ceased to be used for any but the commonest class of wind-instruments. The natural beauty of this wood has sometimes been barbarously destroyed by a dark brown stain.

313. *The Cocus-wood of Jamaica* gives a splendidly brilliant and powerful tone. This wood is extremely hard and resinous, and being therefore peculiarly non-absorbent, it retains its form under the influence of heat and moisture better than any other wood that has ever been tried, but it is prone to cracking, and, owing to its great density, it interferes somewhat with the flexibility of the tone. It has an exceedingly handsome appearance when newly turned and polished, but it becomes dark, dull, and generally unsightly, after being in use for a few years, and the application of French polish only defers the catastrophe for a little while, the ultimate result being worse than when the wood has only received its natural polish.

314. *Ebony* gives a fine tone at first, but it has the chief vices both of box-wood and of the Jamaica cocus, being liable to change in its calibre, like the former, and to cracking, like the latter. This wood is mentioned by Mersenne as being very good for flutes, and it was once popular, perhaps on account of the extreme beauty of its appearance in contrast with silver fittings, but it is no longer used for first-class flutes. Fuerstenau, during the latter part of his career, preferred it to any other wood, having discarded box, but he does not tell us how long his ebony flutes remained in good condition.

315. *Cuban and South American Cocus-wood, or Grenadille.* This material has for many years been employed for the manufacture of flutes. It is excellent for tone-production, though its sound is scarcely so brilliant or so powerful as that of the Jamaica cocus, or so sweet as that of box. Of all known woods it is no doubt the most suitable for flutes, and it is now almost exclusively used. It is nearly as non-absorbent as the Jamaica wood, though less dense, and not so liable to splitting, but it is not by any means free from that risk, and it is not always permanent as regards its calibre, though a flute in my possession, made of this wood by Messrs. Rudall, Carte and Co. in 1874, which has been in constant use ever since, is now even better than when it was new. The bore of this flute has remained quite perfect, but the nature of the wood having been somewhat mollified by age and use, the tone of the instrument has become more mellow and flexible, without being less powerful than at first. I am bound to say that this is an exceptional case. Cocus-wood is found by some persons to produce serious irritation of the lip, which necessitates the use of a silver or gold lip-plate.

316. *Other Woods* have been used for flutes, though not very extensively. Mersenne speaks of "plum-tree, cherry-tree and other woods that may be easily bored," and he says that "it is customary to choose wood of a beautiful colour, which will bear a high polish, to the end that the excellence of the instrument may be combined with beauty of appearance, so that the eye may in some sort participate in the pleasure of the ear."

Quantz (1752) alludes to *lignum sanctum*, now better known by the names *lignum vitæ* and *guaiacum*, as being much used, but Tromlitz (1791) says that though this wood gives a good tone, it has too little elasticity, and is much inclined to crack. *Palissandre*, or violet ebony, an extremely beautiful wood, king's-wood, and rose-wood have occasionally been employed, but not with advantage.

317. *Ivory* was highly esteemed, some years since, as a material for flutes. It does not appear to be particularly subject to decay or to other changes, but it gives a peculiarly hard thin tone, without the powerful resonance so much admired. It probably became fashionable on account of its elegant appearance. Monzani and Hill, Louis Drouet, and several other English and Continental firms, made ivory flutes in considerable numbers.

The famous singer, Madame Dorus Gras, presented an ivory flute with gold keys and mountings to her brother, the eminent M. Vincent Joseph Dorus, formerly of the Paris *Conservatoire*.

Although entire flute-tubes are now seldom made of ivory, this material is still largely used, especially in Germany, for head-joints, and it is useful for those whose lips are liable to irritation by the contact of cocus. Under the circumstances detailed in the next paragraph, there is no great objection to its use for that purpose.

318. *The Lining of the Head-joints* of wooden and ivory flutes with metal, is a custom which has given rise to an immense amount of controversy. This lining was in use in the days of Quantz (1752), who says of it: "Whoever wishes to have the flute shrill, rough, and generally unpleasant, may have it lined with brass, as some have done." Metal head-linings for wooden flutes have been adopted by all the English flute-manufacturers, and most of the performers, for the last seventy or eighty years. They have not generally met with favour in France, though Drouet used them. In Germany they have been only partially adopted, Fuerstenau, however, used one constantly, and wrote in its praise (1832, *post.*). There can be no doubt that the lining materially augments the brilliancy and the power of the tone of a wooden flute, but it causes some slight diminution of sweetness and flexibility. Its chief advantage lies in its endurance, an unlined wooden head-joint being liable to crack and to change its calibre more than any other part of a flute, on account of the heat and moisture to which it is subjected. The chief disadvantage attendant on the use of the lining is the constant fluctuation of pitch caused by the varying temperature of the metal, which, being so good a conductor of heat, not only gives rise to continual change in the general pitch of the instrument, but is apt to cause considerable difference between the temperatures of the upper and lower ends. Much care and skill are necessary to overcome the evil effects of this difference on the intonation. It was once the custom to use tinned brass for head-linings, but Messrs. Rudall and Rose, as this celebrated firm was then styled, introduced the use of silver for this purpose, with manifest advantage.

Metal linings give rise to the necessity for a slightly increased expenditure of breath.

319. *Glass and Porcelain.* Glass flutes have been made from time to time since the days of Mersenne. Claude Laurent of Paris took out a patent for their manufacture in 1806. A more inappropriate material could scarcely have been found. It possesses the single good quality of endurance—until broken. In the Museum of the Paris *Conservatoire* there are two exquisitely finished flutes of Dresden china.

320. *Metals of various kinds* have been used for the construction of entire flute-tubes for many years. William Close of London (1802) possessed "a very small metallic flute," and he gives a description and a representation of "a German flute of the common size constructed chiefly of tin and copper." George Miller (1810) patented "a method of making wind-instruments, commonly called military fifes, of substances never before used for that purpose." The patent was simply for the employment of "a mixture of about one third of copper to two thirds of brass." It appears, from the specification, that military flutes

were also intended to be included in the patent, as well as fifes.

Flutes made entirely of metal have never been very popular, and they seem to have gone out of use until the late Theobald Boehm of Munich re-introduced them in 1847. They were then made in London, Paris and Munich of brass, German silver, silver, and even of gold. Metal flutes have their good and their bad qualities; most of the evil effects of metal head-linings are intensified in instruments made altogether of metal, moreover, there being no covering of wood, the flute gets hot or cold in a moment, and considerable attention on the part of the performer is necessary, or he will be liable to play out of tune. Boehm says truly (1847), that metal flutes are not liable to splitting, but he also says that change of temperature affects them less than it does wooden flutes, an obviously incorrect assertion.

The chief advantage attending the use of metal, is facility of sound-production: the chief disadvantage is shrillness when the tone is forced. Of all the metals ever employed, none equals gold, which has the merits of increasing the chief advantage and diminishing the chief disadvantage above mentioned.

It must be admitted that many of the objections to the use of metal flutes, as they are now made, are purely chimerical and the result of prejudice, but there can be no doubt that they are, and must be, eminently unfitted for orchestral performance. The earlier metal flutes, made after the model of Boehm, were most wretched in tone, as well as in intonation, and it was only after a series of improvements, culminating in 1864, that they became the charming drawing-room instruments they are at present.

321. *Ebonite* embraces more good qualities than any other material ever used for the manufacture of flute-tubes. This valuable and well-known compound, often called vulcanite, consists of India-rubber, sulphur and lead, mixed with a black pigment and subjected to great heat. Its first employment in the construction of flutes is not of recent date, for in the Great Exhibition of 1851 I saw one that was made of it. This was, however, but a very rude instrument and it attracted little attention. About twenty years afterwards Messrs. Rudall, Rose, Carte & Co. undertook the manufacture of ebonite flutes, and these instruments are now more popular in England than any others. If we compare the qualities of ebonite with the list of the requirements of a flute-tube, we shall find that it leaves little to be desired.

Firstly then, in the matter of endurance it may be pronounced perfect, for it is practically indestructible.

Secondly, as it is absolutely non-absorbent of moisture no change in the dimensions of the tube ever occurs, and a metal head-lining is unnecessary.

Thirdly, an ebonite flute invariably improves by judicious use.

Fourthly, this substance possesses just the amount of rigidity necessary for the retention of the enclosed air-column in its proper shape and dimensions, while its own vibrations sympathize so readily with those of the air within, that the sound is produced with as little expenditure of breath as on a metal flute. This latter circumstance renders ebonite flutes peculiarly suitable for the use of ladies, amongst whom the instrument is becoming very popular, and for whom none is better adapted. The excellent and brilliant performer, Miss Cora Cardigan (Mrs. Louis Honig), known as the "Queen of Flute-players," always plays on an ebonite flute. The charming quality of the tone that this talented lady elicits from her instrument is too well-known to need any panegyric in these pages.

Fifthly, this material is so bad a conductor of heat that ebonite flutes are far less affected than any others, in their pitch, by alteration of temperature.

Sixthly, its appearance excels that of the finest ebony, and it generally retains its original lustre with very little attention, though sometimes it loses its extreme blackness.

The practical consequence of all these theoretical perfections is that a flute made of ebonite possesses great endurance combined with capabilities for producing power, softness, volume, brilliancy, sweetness, clearness, flexibility, and general variety

of tone, in a greater degree than one of any other material, a slight reservation being necessary in the case of the single quality of power, and if this is a trifle less than that of a cocus-wood flute with metal head-lining, the other advantages so immeasurably outweigh the exceedingly slight inferiority in this respect, that ebonite must be pronounced the veritable *beau idéal* of the material for the tube of a flute.

322. The proper Thickness for a flute depends so much on the nature of the material employed, and on so many other considerations, that no precise rules can be laid down for its regulation, but it may be taken as a general rule that *cæteris paribus*, the greater the density of the material, the less will be the required thickness. Ebonite allows of more latitude in this respect than any other material with which I am acquainted. It may also be taken as a rule that the greater the thickness of the tube, the greater will be the expenditure of breath required. The thickness that I prefer is .17 inch.

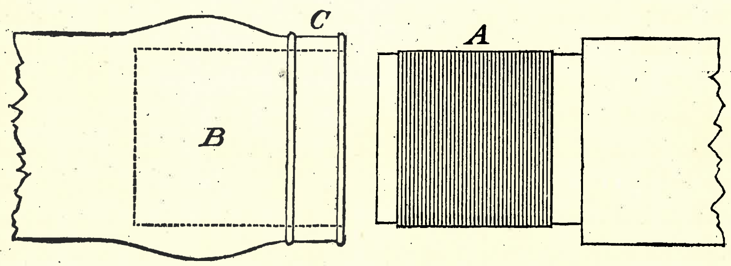
Too great thickness of that part of a flute surrounding the mouth-hole, causes considerable difficulty in the production of the high notes: this, however, is not so much the effect of the actual thickness as of the increased length of the tube which is formed by the mouth-hole.

The following anecdote affords an interesting illustration of the influence of the tube of a wind-instrument on the quality of the tone. A bandsman of the Grenadier Guards, who played the bombardon, an enormous brass instrument with the bell pointing upwards, found his sight injured by the reflection of the sunlight from the bright metal. His instrument was not a good one, its tone being harsh and altogether wanting in richness. As he was not allowed to change it, he was obliged to endure, as best he might, the defects for which it was believed there was no remedy, but, in order to avoid the glare from the polished brass, he obtained permission to paint the instrument black. The effect of the paint on the tone was astounding, for it converted a bad bombardon into a good one by giving the requisite firmness to the tube. See §§243-245 and 247.

323. The *Joints* of the Flute. In the earliest stages of its existence there can be no doubt that the flute was always made in one piece, but Prætorius (1620) gives an engraving of a flute which evidently consisted of two pieces, or *joints*: see *fig.* 41, §403. Quantz says that the flute was not made in three joints until late in the seventeenth century. The number of the parts was afterwards increased to four and to five: the best flutes have now generally three. This division of the tube is desirable for the sake of portability, an extremely convenient attribute of a musical instrument, and one for which the flute has always been pre-eminent. The uppermost member is always termed the *head-joint*, or *head*, and the lowest, when there are three or more, the *foot-joint* or *foot*. The French call this joint *la patte*. The Germans call the second joint the "middle piece," and the third joint the "heart piece."

The members of the flute are united by what is termed a *pin-and-socket-joint*. The pin, *A*, *fig.* 17, was originally bound with

FIG. 17.



waxed thread, technically called "lapping," to cause it to fit tightly into the socket, *B*. The old-fashioned ivory mount is shown at *C*.

The extra thickness at the socket is for the sake of strength. This bulbous excrescence has an inelegant appearance, and is not really necessary. It was discarded in England for many

years, but it has lately been re-introduced, and it is now once more the fashion.

The head-joint generally carries the socket, the pin of the joint below therefore enters in an upward direction, the other joint, or joints, being reversed: sometimes all are made to point downwards, with the idea that the condensed breath may thus be prevented from running into the socket, but if the joint be good it will be water-tight as well as air-tight, and if bad it may as well leak in one direction as another. Thread lapping is still in use on low-priced flutes, but it fulfils its purpose very imperfectly, and the thread requires frequent renewal.

324. In 1812 Tebaldo Monzani, of London, patented an improvement in the joints of wind-instruments, which, however, was common in France some years before that time, and which has long been generally used for first-class flutes. This invention consists of a silver lining for the socket, and a covering of cork for the pin. From the beginning of flute manufacture, it seems to have been usual to apply tips, or ferrules, to the ends of the instrument, and when this was divided the sockets of the joints were protected by similar tips. These were generally of ivory, but sometimes of silver or other metal. When the lapping was discarded it became necessary to give strength to the pin: this is now furnished with a tip.

Pin-and-socket-joints have been, and are still occasionally, made of metal tubes sliding one in the other: these are soon spoiled by the unavoidable friction, and cease to be air-tight or even to hold securely together. Sliding tubes of ebonite stick objectionably, and are therefore extremely inconvenient. The wooden pin, whether covered by thread or cork, will swell, shrink and split. The unlined wooden socket is more liable to split than the pin, notwithstanding the protection of the tip, for it is impossible to keep it dry whether it turn upwards or downwards.

There appears to be but one method of uniting the several parts of a flute-tube, that fulfils the three necessary conditions: perfect fitting, durability, and ease in working, which of course include freedom from liability to shrink, to swell, to decay or to split. All the good qualities above mentioned are secured in an ebonite flute with silver-lined sockets, and cork-covered pins tipped with silver. Here again we may justly say that we have ideal perfection. All cork joints require to be kept well greased; common spermaceti ointment is found to be the best lubricant.

325. Contrivances for altering the Pitch of a Flute. The chief object of dividing the flute into two pieces, appears to have been, at first, the lengthening of the tube between the mouth-hole and the first finger-hole, for the purpose of lowering the pitch. It will be seen that this method could only alter the pitch unequally, for if we remember that the opening of a hole in a flute is equivalent to reducing the length of the tube, and that the rapidity of the vibrations of a column of air is inversely proportional to the length of that column, it must be evident that a note produced from the tube, when shortened by opening a hole at or near its middle, would be lowered in pitch by the above mentioned drawing-out process about twice as much as one produced from its whole length. The only theoretically correct method of altering the pitch of the flute is to change the position of every finger-hole, and this is practically impossible.

Another objection to the partial drawing out of the pin from the socket, is the circular cavity which is thereby left in the bore. The evil consequences of this will be better understood as we proceed. Quantz at one time used rings of different widths to fill up these cavities, an inconvenient custom that has been continued even to our own time.

326. *Extra Middle-joints.* Quantz tells us that it was customary in the last century to use several middle-joints of different lengths for the purpose of altering the pitch of the flute, and that the head-joint was drawn out for intermediate pitches. Tromlitz (1791) recommended as many as seven of these extra middles. I have seen many old box-wood flutes with three. One of these had been a favourite of Theobald Monzani, and afterwards belonged to Cornelius Ward, who showed it to me. The large, baize-lined, mahogany case that contained it, bore an inscription, which, as far as my memory serves me, set forth the facts that a horse and chaise, valued at one hundred and fifty guineas, had been offered for this wonderful flute, and refused!

Quantz thus explains a contrivance that was intended to remedy the unequal flattening of the pitch by these extra joints: "Not long ago, a plan was invented by means of which the foot-joint was made in two pieces, so that, like a needle case, it could be pulled out, or pushed in, half an inch. The object seems to have been that for each shorter middle, the foot should also be made shorter, and that therefore the flute, by means of the extra middles, should be capable of being made a whole tone higher or lower. This invention, had it succeeded, would have been valuable, but as by altering the length of the foot, only the pitch of the *D* is changed, all the other notes are rendered false . . . therefore this should be discarded." For some inscrutable reason this slide was called by Tromlitz, a noted flute-player and manufacturer of Leipsic, a *register:* its use was strongly advocated by him, and he gives an engraving of it (1791).

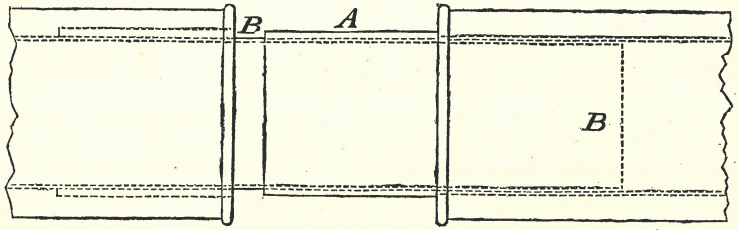
This unqualified condemnation of the register by Quantz appears rather too sweeping, as although the contrivance was only a partial remedy, yet it must certainly have somewhat ameliorated the evil effects of lengthening the tube above the finger-holes, for not only would the *d'* have been improved by the use of the register, but the *d''* also, as well as many notes in the third octave, and the great discrepancy between the *c''*♯ and the *d''*, caused by elongating the part of the tube above the *c''*♯ hole, would have been removed.

327. *The Tuning Slide.* Quantz, in his *Essay* (1752), says that it is useful to have the head-joint divided by an additional pin-and-socket-joint, of greater length than the others, for the purpose of flattening the flute more conveniently than by lengthening it between the head and the second joint. In his autobiography (1754) he claims this as his own invention, considerably exaggerating its advantages.

A thin metal slide was shortly afterwards substituted for the wooden one, and this was a great improvement, as the drawing out of the tube left no appreciable cavity, and therefore the necessity for introducing rings was avoided.

FIG. 18.

Metal Tuning Slide.

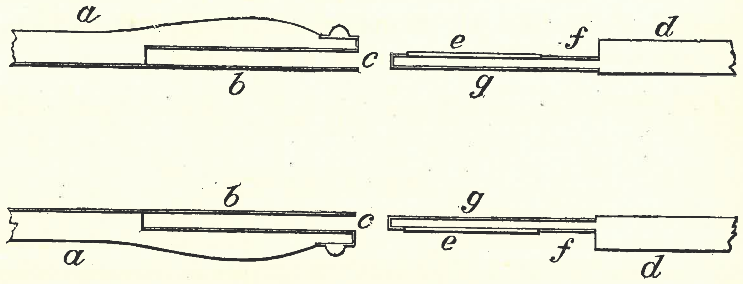


A. Metal tube in which slides the smaller tube, *B B.*

The above figure shows a common form of this useful invention, which appears to have been in general use towards the close of the last century. Other forms of the tuning slide will be found hereafter figured and described. The inner tube is now often a part of the head-lining, but sometimes it penetrates only a short distance into the head-joint. This plan is the best for an ebonite flute, but the tube should pass completely through the head of a flute of wood, for the reasons already assigned, and also because otherwise it is almost certain to become loose.

The best kind of slide forms part of the ordinary pin-and-socket-joint, and one pattern of this slide has been common in France for many years. That shown below is an improvement by my esteemed friend, the late John Mitchell Rose, of the old firm of Rudall and Rose.

FIG. 19.



a a. Section of part of the head-joint.

b b. Silver tube to fit inside the pin, for the purpose of covering the cavity left when the flute is elongated.

c c. Socket, lined with silver.

d d. Section of part of the middle-joint.

e e. Pin, lined with silver, and covered partly with cork, at *e e,* and partly with silver, at *f f.*

g g. Silver lining.

This combination of tuning slide and joint answers well for wooden flutes, but much better for those of ebonite on account of the equable nature of the material, and in these it is practically perfect.

Although every tuning slide must be pronounced theoretically at variance with correct principles, yet the head-joint of a judiciously constructed flute may be extended a quarter of an inch beyond its normal length, flattening the *a'* rather more than an eighth of a tone, without causing any great detriment to the intonation of the instrument, and here shines out one supreme advantage possessed by the flute over other wind-instruments. It has been explained how the upper notes of each octave become flattened more than the lower ones when the upper portion of the tube is elongated; now, by blowing the flute sharper than its mean pitch, the upper notes of each octave are made sharper, in comparison, than the lower notes; thus, with reasonable care and skill, perfect compensation may be attained, but it becomes intensely difficult to preserve the intonation if the above mentioned limit be far exceeded, and the difficulty is of course increased in direct proportion to this excess. It will be presently seen how additional compensation may be obtained.

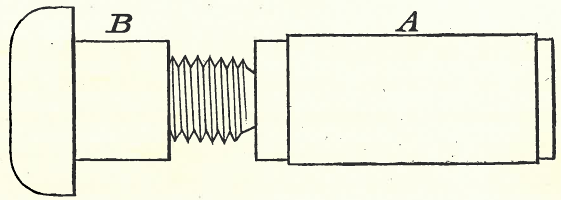
328. The Cork, or Stopper. In §87, it is stated that one end of the flute is of necessity closed. The partial or complete closing of one end of a wind-instrument is absolutely essential for the production of any sound of a really musical character: see §160. As the position of the stopper is a matter of vital importance, and as circumstances frequently arise which render it necessary to change this position, it is desirable that convenient means should be afforded for its adjustment.

329. *Material and Construction of the Stopper.* The closing of the upper end of the flute appears to have been originally effected by means of a cork. This substance is still used for the purpose in low-priced English flutes, and I believe in most of those made abroad. It is a peculiarly inappropriate material, as it is subject to continual changes of calibre in different degrees of moisture. Wood enclosed in a hollow cylinder of cork, and faced with silver at the lower end, is generally used in the best English flutes, but such a stopper does not answer perfectly, as when wet it will swell and stick fast, and when dry it will shrink and fall out of its place. Ebonite, with cork covering, forms the best stopper, and may be pronounced perfect, as far as materials are concerned.

330. The well-known "screw-stopper," shown in figure 20, was in use before 1752, and it appears, from the description of it given by Quantz, to have been made in his time on precisely the same principle as at present. Its use was well understood and carefully explained by him. He, however, laid no claim to the credit of having invented it, and he does not appear to have regarded it as a novelty.

FIG. 20.

Best form of Screw-Stopper.



A. Screw-stopper, partly enclosed in a cylinder of cork. *B*. Screw-cap, or button.

This stopper, when well made, is all that can be desired, but the cork covering, like that of the joints, requires the occasional application of a lubricant.

Sometimes a peg, which forms part of the stopper, and sometimes the screw itself, protrudes through the cap. The projecting part is intended to indicate the position of the stopper, but in the case of a substance of such variable calibre as cork such an appendage can only be misleading, and under no circumstances is it necessary, the normal position of a properly constructed stopper being secured when the cap is screwed home and pressed closely into the head.

331. *The Position of the Stopper.* Theoretically, the stopper should be in a different place for every note of the scale, but as this is practically impossible we have to be content with a temporarily fixed medium position which may be changed under certain conditions. It has been found by experiment that the best results are obtained, on a well-tuned flute, when the cork is placed at a distance equal to its own diameter from the centre of the mouth-hole. A greater distance than this will cause the second octave to be too flat, and, while giving some increase of power and firmness to the low notes, will render the third octave difficult to sound and impossible to play at the same time softly and in tune. If the cork be too near the mouth-hole the second octave will be too sharp; the low notes will be weak and unsteady, and the third octave, though easy to sound, will be too sharp. If the finger-holes be correctly placed, any deviation from the true position of the cork will throw the whole instrument out of tune, even as regards the relation of the notes of each separate octave to each other.

332. The effect of the position of the stopper on the pitch is far greater on the upper notes of each octave than on the lower notes, it is also proportionally greater in the second octave than in the first, and greater still in the higher harmonics. This varying influence affords a means of correcting, to some extent, the intonation of badly tuned flutes, whether the errors happen to be the result of imperfect construction, or of the drawing out of the tuning slide. It is impossible to lay down hard and fast rules for altering the place of the stopper, as the extent of the change that may be necessary will depend in a great measure on the proportions of the bore, but it may be roughly stated that the stopper should be *pushed in* to an extent varying from an eighth to a quarter of the distance of the *drawing out* of the slide.

333. The Mouth-hole, or Embouchure. Considering the important functions of the mouth-hole of a flute, it may seem not a little surprising that considerable latitude may be allowed, as regards its form and dimensions, without seriously affecting its efficiency, but the reasons are really not far to seek, as a skilful player acquires the power of regulating his lips so as to suit almost any form of mouth-hole, and the size of this aperture is easily modified by the simple process of covering it more or less by the lower lip. The mouth-hole was originally circular, and this shape seems to have been generally retained until the present century, but there is indisputable evidence that elliptical mouth-holes were used in 1724. In recent times they have been made of widely differing shapes and dimensions. Their form has varied, in every conceivable gradation, from round to oval, to oblong and to square. Their sides have been convex, perpendicular, or *undercut* to the extent of forty-five degrees. The diameters of circular mouth-holes have varied from .25 to .4 inch

and of those of oval and oblong form, from .375 to .562 inch, and from .25 to .44 inch. These measurements are those of concert-flute mouth-holes that have come under my own observation. I have never seen a square one. The mouth-holes of the smaller instruments are generally less than those of concert-flutes.

334. A mouth-hole of large size affords an excellent means of correcting the defects of an imperfect instrument, and at the same time gives great scope for the management of the *crescendo* and the *diminuendo*, but it requires considerable skill and experience on the part of the performer, and, all things considered, moderate dimensions are the most desirable. For a concert-flute, the length of the mouth-hole should be .5 inch, and its width .42 inch.

335. As regards shape, the oval is now generally used, and I consider this to be theoretically, as well as practically, the best, though many good performers prefer the oblong. If we reflect for a moment on the fusiform aperture between the lips of the player, and the natural convexity of the lips themselves, it will be obvious that an edge concave towards the labial aperture, is better fitted to be the intermediary between the excursions of the air-reed than a straight one. See chapter III. As a practical fact, I find that an oblong mouth-hole does not afford nearly the same facility for the modification of tone and intonation as an oval one, although performers who adopt a different method of lip management may find some advantage in the oblong shape.

336. The *undercutting* of the mouth-hole slightly facilitates the production of the high notes, but, if carried too far, the tone of the lowest octave becomes seriously injured in power and volume.

Convexity of the walls of the aperture detracts from the power and certainty of the tone, and is attended with no advantage that I have been able to discover; it must also be regarded as wrong in theory.

A diagram of a perfect mouth-hole is given in §87, *fig.* 6.

337. The anterior portion of the edge of the mouth-hole should be moderately sharp. In order to preserve it in this condition the hole is occasionally *bushed*, or lined, with some hard substance, such as ivory, horn, "mother of pearl," or metal. This lining is sometimes useful, particularly in the case of accidental injury to the edge of the hole.

A gold or silver lip-plate, entirely surrounding the head-joint, is useful for those persons who have extremely sensitive lips, and who use cocus-wood flutes. I am not aware of any other material that irritates the skin. A small lip-plate let into the flute is not safe, as it often becomes loose round the interior of the hole, and in that case the tone of the instrument is certain to suffer.

338. The Bore. *Its Various Forms.* Before entering upon an account of the advantages and disadvantages attendant upon certain variations in the bore of the flute, it may be well to remind the reader that although the extreme upper end of this instrument is always completely closed by the cork, yet the mouth-hole converts the tube into what must be considered, from an acoustical point of view, an open one; the series of harmonics is therefore complete.

The late Theobald Boehm of Munich (1847, pp. 44 and 51, Eng. Ed. pp. 33 and 39) asserts that the portion of the tube between the mouth-hole and the cork should be regarded as a stopped tube, and should therefore be reckoned as double in all calculations for length; but although this part of the bore may be said to be stopped at one end, according to the ordinary meaning of the words, it is nevertheless so far from being so, in an acoustical sense, that its effect on the pitch is not nearly equal to that of half a similar length of open tube. As a matter of fact, the vibrations of that part of the column of air which is above the mouth-hole are so extremely feeble and uncertain that they can scarcely be taken as elements of calculation at all. These vibrations appear to be somewhat similar in their nature to those that extend beyond the lower end of the instrument (see § 124), and to be even less understood. If the part of the tube in question

were stopped, in an acoustical sense, there would be a node at the cork, and such an idea is contrary to reason and experience: see §159.

All flutes, whether large or small, had originally cylindrical bores. It has been so often asserted that cylindrical flutes of full concert-size have no musical value, that it now seems to be generally taken for granted that the assertion is true, whereas it is entirely without foundation. A concert-flute with a bore that is entirely cylindrical gives an extremely powerful tone throughout its three octaves, and by careful adjustment of the cork and the finger-holes it may be rendered perfectly in tune. In 1637, according to Mersenne, cylindrical flutes were made to extend a full octave below the concert-flute, and they would consequently have been about double its length. The chief fault of a cylindrical flute lies in the character of its tone, which seems harsh and unpleasant to ears accustomed to the exquisite sounds of our modern instruments.

339. I have found it impossible to discover the precise date at which the bore was first changed in shape. It was probably made entirely or partly conoidal towards the close of the seventeenth century, and it seems not unlikely that the author of the improvement was either Johann Christoph Denner, a famous wind-instrument maker of Nuremberg who invented the clarionet in 1690, or one of the celebrated family of the Hotteterres: see §416.

Since this change was effected and became known, it would appear that no flutes other than military fifes were made entirely cylindrical, and even these are seldom thus constructed at the present time.

The contraction of the bore was at first made towards the lower end. Louis Hotteterre, surnamed "*le Romain*," the most celebrated flute-player of his time, used in 1699 a flute of which the head-joint was probably cylindrical and the remainder was certainly conoidal. Five-and-twenty years later Quantz was using a cylindrical head-joint with conoidal continuation, and it is evident that in his time flutes were generally thus made, though the distinguished mathematician, Lambert (1775), gives a carefully executed engraving of his own flute, each joint of which was conoidal. According to his description: "*chaque partie est un conoid tronqué.*"

Shortly before 1782, J. J. H. Ribock of Lüchow near Lüneberg, a Doctor of Medicine and an enthusiastic amateur flute-player, attempted to improve the bore of the flute. He described his experiments in a small treatise (1782), an account of which will be found in §§466 to 470.

The conoidal portion of the bore of the "conical flute" is seldom regular in its declination, for the upper part of each joint often expands or contracts suddenly, and the gradual contraction afterwards continues, more or less irregularly. From a point near the terminal opening, the conoid is generally inverted, but sometimes this part of the bore is cylindrical. The lines of the conoidal bore are often considerably curved convexly, especially near the middle of the instrument.

All contractions of the bore weaken the tone of the notes which particularly depend upon the portion contracted, but they are not on that account to be unreservedly condemned, for it cannot be denied that great benefits are derived from the judicious reduction of the diameter of some part of the tube, as not only is the tone thereby rendered more flexible and mellow, but less expenditure of breath is required in its production.

340. It would be tedious to describe the effects of small irregular variations in the bore, especially as no theory has ever been successfully established with regard to them. Even Lord Rayleigh (1878) says that "when the section of the pipe is variable the problem of the vibrations of the air within it cannot generally be solved." Much was, however, done by actual experiment to improve the defective notes of the older instruments by "chambering," or slightly enlarging, the bore at certain places. Some of the flutes made by the old firm of Rudall and Rose were marvels of ingenuity in this respect.

The proportions of one of the best amongst the numerous

so-called conical bores of concert-flutes, are as follows: The cylindrical part extends for about one-third of the length of the tube; from that point the tapering begins, continuing in perfectly straight lines which converge sufficiently to reduce the diameter of the bore at the terminal opening to rather more than one-half that of the cylindrical part, supposing the flute to be made of sufficient length to give *c'*. The contraction is, however, sometimes not more than enough to reduce the diameter by one-third, and it is seldom completely carried out, for the bore is generally caused to expand from a point about two inches, or less, above the open end. This expansion confers greatly increased power on the lowest note.

The chief advantage of the conoidal bore was the improvement of the third octave, some notes of which, especially the *a'''*, were exceedingly incorrect on the older flutes, on account of certain defects in the arrangement of the finger-holes which prevailed at the time that the change of bore was effected. The evil consequences of these defects were somewhat reduced by the above-mentioned contraction.

It must be admitted that the old cylindrical head-joint and the conoidal continuation have many advantages, and they should not be lightly condemned. Some of the finest performers that ever delighted the world played on these flutes and could not be persuaded to relinquish them, and many excellent players still prefer them. Piccolos of this kind are certainly superior to any others.

341. In 1847 Theobald Boehm reverted to the long disused cylindrical shape of the lower and greater portion of the bore, and reduced the diameter of the head-joint at the upper part. This form of bore, combined with other changes described in subsequent pages, gave rise to a decided improvement in the character of the tone, accompanied, however, by some loss of power, particularly in the third octave, and, on account of the greater length of the cylinder, a slight increase in the force of the breath became necessary, particularly for the production of the lower notes.

As far as I have been able to discover, all improvements that have ever been effected in the bores of wind-instruments have been absolutely empirical. According to my experience the best results are to be obtained from a tube which is cylindrical for nearly four-fifths of its length, the upper part being curvilinearly reduced, so that the diameter at the cork becomes about one-ninth less than that of the cylindrical part. Boehm (1847) considered that the contraction should begin at "the upper sixth part of the whole length of the tube." In many recently made flutes the contraction extends for one-quarter of the length. Considerable latitude may be allowed in the proportions of the curve, and the upper part of it may be, and often is, nearly conical. The part of the tube, into which the cork is fitted, should of course be cylindrical. The usual curve is popularly supposed to be parabolic, and flutes bored as above described are commonly known as "cylinder flutes with parabola head-joints."

Although the preference may generally be given to this form of the bore, yet, unless the finger-holes be of considerably larger size than is possible with the conoidal form, the latter affords the greater number of advantages. This matter will be further explained in the part of this book devoted to the subject of the finger-holes. The form of the bore being in some degree a question of taste and circumstances, it would be wrong to attempt to lay down hard and fast rules for its determination.

342. *The Dimensions of the Bore.* It is a curious fact that the diameter of the largest part of the bore of a concert-flute has remained almost the same for a period of at least two centuries and a half. Cornelius Ward (1844), a man of great experience, states that "the largest and the smallest do not differ more than about a thirtieth of an inch." The earliest recorded dimensions of the bore of a flute are, I believe, those given by Mersenne (1637). Reducing his measurements, which are in fractions of the old French foot (or *pied de roi*), to English inches, we find the bore of "one of the best flutes in the world" to have been .71 inch. This flute was cylindrical throughout, and from

its length, 23.45 inches, we may assume that it was a concert-flute of the period. The mean diameter of the head-joint of Lambert's flute (1775), which is given by him in lines of the old Rhenish foot (or *pied de Rhin*), was nearly .74 English inch. The bore of this head was, as before stated, conoidal. The head-joints of the flutes of William Henry Potter, the most celebrated English manufacturer at the beginning of the present century, measure from .74 to .75 inch. Those of the early flutes of Rudall and Rose were very nearly of the same size, and the conoidal flutes of the present firm, Messrs. Rudall, Carte and Co., show no appreciable difference. The well-known "Nicholson flutes" were rather smaller in the bore than most others of English manufacture. The head-joints of these varied from .73 to .74 inch in diameter. The French flutes have generally been smaller in the bore than those of England and Germany, particularly at the beginning of the contraction. At this place the difference of diameter has been greater than in any other part of the bore. Theobald Boehm gives the diameter of the head-joint of his flute of 1832, as 18.4 millimeters, or nearly .73 inch. In 1847 the cylindrical portion of his flute measured 19 *m m.*, or nearly .75 inch. Thus we see that between the widest and the narrowest of all these head-joints there is but a difference of .04 inch.

The diameter of the tube is of vital importance as regards the pitch, the power, and the facility of the production of the sound: see §§154 and 155. The general character of the tone is also considerably influenced by the size of the bore. If this were too large the tone of the fundamentals would be hollow, and the upper notes not only difficult to produce but nasal in tone; the lower attendant sounds would be very prominent, and the tone inflexible throughout the compass of the instrument. On the other hand, too narrow a bore would cause the tone to be thin, especially in the lowest octave, where the prominence of the partials would be excessive.

Whether the cylindrical portion of the bore be above or below, a diameter for this part of from .74 to .75 inch, gives the best general results. In the latter case the narrowest part of the head-joint should measure about .67 inch.

343. The Finger-holes. All lateral openings in a flute, except the mouth-hole, are closed or opened, directly or indirectly, by the fingers of the player, whether used as note-holes or as vent-holes, hence they are conveniently called by the general name, *finger-holes*. In order to avoid confusion each finger-hole will be invariably named after the fundamental note given by the flute when that hole is open and all those above it are closed.

Leaving for future chapters the discussion of the imperfect distribution of the finger-holes of the primitive flutes, and also the enumeration of the tardy and uncertain steps of those who have sought to improve that distribution, I have thought it desirable, in this place, to explain the correct principles for the division of the tube as applied to the best concert-flutes of our own time. It will scarcely be necessary to call attention to the fact that correct intonation is the most important desideratum for every musical instrument, or to repeat that the intonation of the flute depends chiefly on the diameter and the distribution of the finger-holes.

Now, the influence of position alone is sufficient to regulate the intonation, while the character and the power of the tone depend much on diameter, therefore the question of the most suitable diameter should be first decided. It is assumed that the reader is familiar with what has been said in chapter IV., especially that part of it which treats of note-holes and vent-holes.

344. A flute worthy of the name must be so constructed as to enable the performer to produce, without undue effort, a reasonably perfect chromatic scale, according to the system of equal temperament, throughout the entire compass of the instrument. Not only must this chromatic scale be well in tune, but the tone of all its notes must be equally powerful and of uniform quality, besides being sufficiently flexible to admit of its being produced with extreme softness. Certain of these points of excellence

have been shown to depend in some measure on various conditions already sufficiently explained, but without a near approach to absolute perfection in the arrangement of the finger-holes, excellence in other matters is of no avail.

In order that a good chromatic scale may be possible, each note must have a separate hole for the determination of the requisite length of tube, and each hole must be of a certain diameter which must be regulated according to various complex and conflicting conditions. If the compass of the flute were but two octaves, the finger-holes might be graduated in size, becoming smaller as they approached the mouth-hole, with advantage to equality of tone and to facility of performance; as, however, most of these apertures have to fulfil the duty of vent-holes as well as of note-holes, it is imperative that they should be of uniform diameter, except in the case of the *c''*♯ hole and of certain supernumerary *d''*♮ and *d''*♯ holes, which require to be made much smaller than the others. The reasons for this general uniformity, and for the occasional deviation from it, will appear in subsequent pages of this chapter. The supernumerary holes are described in §§365 and 366. At present we have to discuss the holes from the *c''* hole downwards, and to consider them only as note-holes.

345. *Diameter of the Finger-holes.* The chief points to be considered in the determination of the diameter most desirable for finger-holes, regarded simply as note-holes, are, as before stated, the character and the power of the tone. The requisite size for the holes being decided, the tuning must be effected by the judicious arrangement of their several positions. After many careful experiments, I arrived at the conclusion, about twenty-five years ago, that, all things considered, the diameter of the finger-holes of the quasi-cylindrical concert-flute, the bore of which is described in §§341 and 342, should be approximately .64 inch, or nearly $\frac{6}{7}$ths of the cylindrical diameter of the bore.

A hole appreciably larger than this cannot be used with advantage for *c''*, and therefore, granting the necessity for equality in the diameter of the holes, it is the largest that should be used for any note. A clear demonstration of the evil quality of tone caused by too large an aperture can be readily obtained by removing the foot-joint of one of these flutes, and testing the sound given from the open end, which will have an opening only .11 inch wider than the above-mentioned finger-holes, yet the tone from the open end of the flute will be wild and harsh compared with that from the finger-holes. If the experiment be carried further by sounding the head-joint alone, an eminently disagreeable tone will be the result. An aperture of .64 inch, though it will give *c''* with an excellent tone, will give an unpleasant sound if used for *c''*♯, though of course less unpleasant than that from the open end of the head-joint. The worst note of the so-called cylinder flute is the *c'* from the terminal opening, notwithstanding the distance of this from the mouth-hole.

Independently of other considerations, the alteration in the shape and proportions of the bore caused by the recesses of the closed holes, though not practically so detrimental as might have been expected, is nevertheless too important a matter to be altogether disregarded, and when the diameter of the holes is carried appreciably beyond the limit given above, the tone suffers seriously. The practice of undercutting the finger-holes is injurious for the same reason, and is only to be tolerated as a means of correcting some of the evil effects of ill-regulated positions.

Finger-holes of .64 inch in diameter enable the player to produce the greatest power of tone with a given expenditure of breath; they are peculiarly well-adapted for metal flutes, and they permit the advantageous employment of a tube of greater thickness, whatever may be the material, than would be desirable with smaller holes. It has been asserted that these large holes give rise to "wildness" in the tone, an assertion without the smallest foundation in fact. A wild, or unmanageable, tone is generally the fault of the player, not of the instrument, and the most frequent cause of this evil quality is violent blowing in the attempt to obtain

a powerful tone from a flute with holes of insufficient size. Besides a large number of excellent performers, both amateur and professional, who prefer the large holes, the gifted lady, to whom allusion is made in §321, has always used them, and it is impossible to imagine a tone more perfectly flexible or freer from wildness than hers.

Forty-five centuries ago, according to Chinese tradition, the finger-holes of certain wind-instruments were made as large as the bore (see §302), but holes of uniform diameter, as large as .64 inch, were never applied to flutes until so applied by myself in 1864.

346. Finger-holes appreciably less than .64 inch cannot be employed with advantage for the kind of flutes under discussion, as they cause the tone to be poor, both in character and power; they also render it more difficult to make the harmonic octaves sufficiently sharp to agree with the fundamentals. The difficulty thus caused is inversely proportional to the distance between the note-hole and the mouth-hole. In the case of the higher harmonics the effect is much more marked, the harmonic fifteenth, or double octave, may be made quite a semitone too flat by reducing the size of the aperture. It may be thought that this defect might be remedied by decreasing the distance between the cork and the mouth-hole, but it will presently be seen that the ordinary notes of the third octave would be thereby rendered unbearably sharp.

The finger-holes of the so-called conical flutes, except that for *c''*♯ and the supernumerary holes before mentioned, should also be equal in diameter, therefore their limit must be that of the smallest part of the bore, about .4 inch. It will be understood that the holes of the smaller flutes should be proportionately less than those of concert-flutes.

347. *Veiled Notes.* Whatever may be the form of the bore or the diameter of the finger-holes it is absolutely imperative that there should be sufficient freedom of opening, below the hole that immediately determines the length of tube, to cause the necessary amount of abruptness in the termination of the column of air. It is customary to call sounds which are spoiled by inadequate openings, *veiled notes*, and this veiling is always mentioned in terms of condemnation, yet it must be now evident that, without the softening effect of partial veiling, agreeable sounds could not be obtained, but of course the veiling must not be carried too far, or the tone will be dull and weak; in fact, destitute of any good quality. There are, however, certain circumstances in which the veiling of a note even causes an accession of power. I confess at once my inability to give a reason for this, and I am not aware that anyone has ever attempted to do so, but the fact is indisputable. "*Causa latet: vis est notissima.*"

348. *Positions of the Finger-holes.* The most desirable size for the finger-holes being determined, we have next to consider that which must be pronounced one of the most important, and at the same time one of the most difficult problems connected with a wind-instrument, namely, the correct positions of the finger-holes. It will be convenient still to consider these as note-holes only.

The best mathematicians that have investigated the subject, including Professor Zamminer, (1855B), have emphatically proclaimed the impossibility of finding the correct positions of the finger-holes of any wind-instrument, *ab initio*, by calculation. M. Cavaillé-Coll (1860) invented some ingenious theories for determining the lengths of organ-pipes, and he obtained close approximations to accuracy, but even in the case of pipes intended to give but one note each, the services of the tuner are always required for the final adjustment. In the case of the lateral perforations of wind-instruments, all attempts to found calculations for position on the divisions of the monochord are fallacious, and to claim the credit of having achieved success savours somewhat of charlatanism, for it would be necessary to modify the calculations for the length of the tube by taking into consideration the varying influences of the density and the thickness of the material; the width and the proportions of the bore; the form and the dimensions of the mouth-hole; the

diameter of the finger-holes, and numerous other matters which form a combination of difficulties that mathematical science has not yet successfully attacked.

349. Some notice has been attracted by a paper on this subject by Professor Schafhäutl, an intimate friend of Th. Boehm's. I have not seen it, for after reading the following criticism by Mr. Ellis, I did not think it likely to be worth the search. "The paper by Schafhäutl (writing under the name of Pellisov): '*Theorie gedeckter cylindrischer und conischer Pfeifen und der Querflöten,*' *Schweiger Journ. LXVIII.*, 1833, is disfigured by misprints so that the formulæ are unintelligible, and the theory is also extremely hazardous."

Theobald Boehm affirmed (1847 and 1868) that he had discovered the solution of the problem, but no unprejudiced reader, at all conversant with the subject, could possibly endorse his opinion, moreover, his flutes were not made according to his figures; had they been so made, they must have been even more out of tune than they were. I know of two attempts to make flutes according to his "*schema*" (1868): the result of the first experiment was pronounced "ghastly" by the gentleman who tried it, an eminent flute manufacturer. I was a witness to the complete failure of the second experiment, which I know to have been most carefully and conscientiously conducted. Boehm, by his own account, first endeavoured to obtain correct measurements, by "rule of thumb," and he then sought a theory to fit them. In both attempts he failed, for his practice and his theory were not only incorrect, but they were totally incompatible with each other. After the perusal of his writings, however, one can scarcely feel astonished at his want of success.

A common error of those who pretend to construct scales for the positions of note-holes by calculation alone, is that of assuming constancy in the influence of the partial closing of the upper end of the tube by the substitution of the mouth-hole for an open end, whereas the fact is that this influence varies inversely as the distance of the note-hole from the mouth-hole, and it varies to such an extent that the *c''*♯ of a flute is affected by it nearly twice as much as the *c'*♯.

350. It stands to reason that the true position of every finger-hole of a flute may be found by actual experiment, but this method is tedious as well as costly, and, unless carried out with extreme care and skill, it is uncertain. The desired result may be attained in a more simple manner by finding, experimentally, the positions of certain holes as data, and then completing the division of the tube by calculation. An example of this method is here given.

In the annexed scale, the note *c'* with vibrations 268.760 is considered to be determined by a lateral aperture of .64 inch in diameter, the centre of which is distant from the centre of the mouth-hole 22.678 inches. The flute is supposed to be of ebonite, with a tube of .17 inch in thickness; a bore of the most approved quasi-cylindrical form, of the dimensions and proportions described in §§341 and 342, and an elliptical mouth-hole, the diameters of which are .5 and .42 inch respectively. All the finger-holes are assumed to be of equal diameter, and the keys are assumed to have the usual uniform rise (see §388); the distances between the holes are reckoned from centre to centre, and are given in decimals of an inch, a form of expression that is likely to be more familiar than millimeters to most English readers. The instrument is supposed to be raised to the temperature which it usually attains during performance.

In order to obtain the indications for the absolutely correct tuning of the scale, it is necessary to find, by direct experiment, the true positions for three of the finger-holes. It will be convenient if two of these be adjacent holes, at or near the lower end of the scale, and if the third be as far removed from them as possible. Under the conditions given in the present section, the true distance between the *c'* and the *c'*♯ holes will be found by experiment to be 1.426 inch, and that between the *c'* and the *c''* holes will be found to be 12.528 inches. By working upwards from *c'*, and making each successive distance

$\frac{1}{17}$th less than the preceding one, the positions for all the holes, requisite for one octave of the chromatic scale, may be obtained. The sum of the twelve distances will be 12.528 inches, the calculation agreeing precisely with the experiment. It follows that in calculating downwards, successive augmentations of $\frac{1}{16}$th, or $6\frac{1}{4}$ %, will indicate the required positions for the holes. The figures for the complete scale will be found in the next section.

When the open end of the flute is intended to give *c'*, its correct distance from the *c'*♯ hole is 1.58 inch, but as only the lowest note is dependent on this opening, and as this note is a troublesome one to manage in a *pianissimo*, I prefer to have it tuned rather sharp. There is not much difficulty in keeping it flat enough, even in a *fortissimo*.

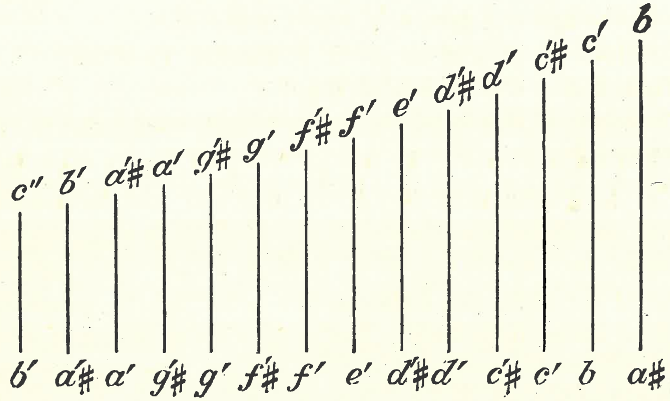
It will be seen, from the following figures, that the distances from the *c''* hole to the *b'* hole, and from the *b'* hole to the *a'*♯ hole, are considerably less than half the distances for the corresponding note-holes of the octave below. Boehm's ideas on this matter (1868) are egregiously incorrect; again his theory and his practice are at variance, and again both are wrong.

351. This scale is calculated to the nearest $\frac{1}{1000}$th part of an inch, therefore the greatest error can amount to no more than $\frac{1}{2000}$th of an inch, an approximation to accuracy only necessary in order to prevent the accumulation of error, as such an exceedingly minute deviation from absolute truth is inappreciable in practice, and represents an average error of little more than $\frac{1}{40}$th of a schisma.

Placed at equal distances and parallel to each other, the divisions of this scale appear as in *fig.* 21.

Note-holes.	Inches.
c''	
	.731
b'	
	.777
a'♯	
	.826
a'	
	.878
g'♯	
	.933
g'	
	.991
f'♯	
	1.053
f'	
	1.119
e'	
	1.189
d'♯	
	1.263
d'	
	1.342
c'♯	
	1.426
c'	
	1.515
b	
	1.610
a♯	

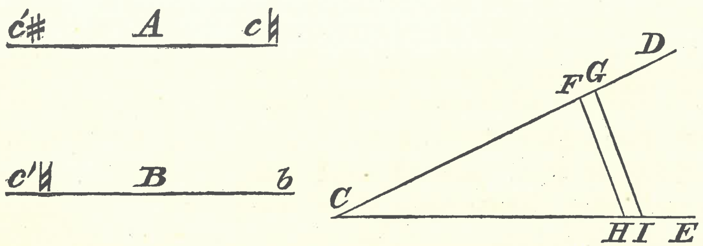
FIG. 21.



351.* The truth of the above proportionals may be proved geometrically by the following simple and well-known problem:

Let *A*, *fig.* 22, represent the distance from the *c'*♯ hole to the *c'*♮ hole, and let *B* represent the distance from the *c'*♮ hole to the *b* hole. It is required to find a third proportional to *A B*. This will be the correct distance from the *b* hole to the *a*♯ hole.

FIG. 22.



I. From any point, *C*, draw two straight lines, making any convenient angle, *D C E*.

II. In the line *C D* take *C F* equal to *A*, and *C G* equal to *B*. In the line *C E* take *C H* equal to *B*.

III. Join *F H* and draw *G I* parallel to *F H*.

Then *C F* : *C G* :: *C H* : *C I*.

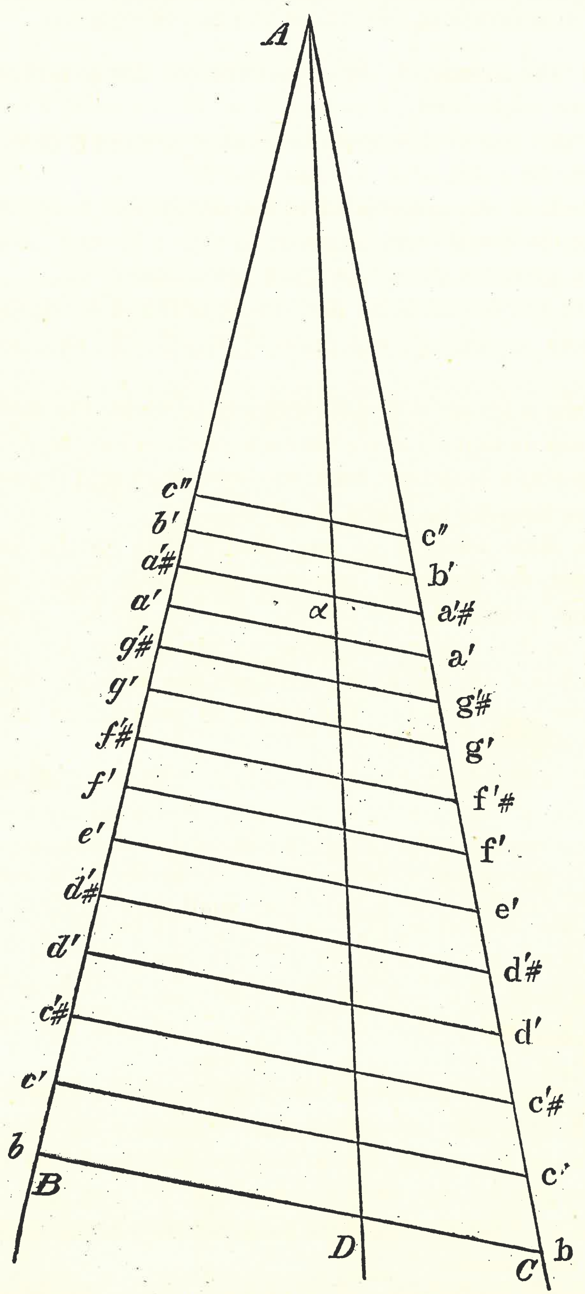
Therefore *C I* will be the third proportional required, and will represent the distance from the *b* hole to the *a*♯ hole.

The true positions for the note-hole for *c''* and for any three lateral note-holes near the opposite end of the flute, having been obtained by experiment, it is possible to set out a complete scale of the distances between the holes by the geometrical method above described. The proof of the accuracy of the result will be the perfect coincidence of the point for the centre of the *c''* hole, with that found for the same by experiment. The geometrical method, though perhaps less tedious than that explained in §351, particularly to those persons who are not fond of figures, is obviously less free from liability to error; it entails, moreover, the necessity for further recourse to the troublesome process of experimental tuning.

352. The *proportions* given in §351 are adapted for "cylinder flutes" of any material, thickness, or pitch, with equal sized finger-holes. In order to find the *actual* distances, it is necessary to determine, as before stated, by direct experiment, the correct position for a hole that shall give any note of the required pitch; the positions for the remainder of the holes may then be found by the following simple modification of another geometrical problem as well-known as the former one, in fact a mere extension of it.

The scales in *figures* 23 and 24 are reduced to one-quarter of their normal length.

FIG. 23.



I. Let any point, *A*, *fig.* 23, represent the centre of the mouth-hole of a flute. From *A* draw the straight line *A B* and, at any convenient angle to *A B*, the straight line *A C*.

II. Let the point *c″* in the line *A B* be distant 10.15 inches from *A*, which will correspond to the distance of 22.678 inches from *c′* to the mouth-hole, as given in §350. From *c″*, with the distances given in *fig.* 21, set out the scale *c″ b*.

III. On the line *A C* let *A* c″ be equal to *A b′* on the line *A B*. Join *c″* and c″ and draw *b′* b′, *a′*♯ a′♯, etc., parallel to *c″* c″.

Then the scale on *A C* will evidently be divided in the same proportions as that on *A B*, but each position indicated in *A C* will represent a sound one semitone lower than that represented on the corresponding point in *A B*.

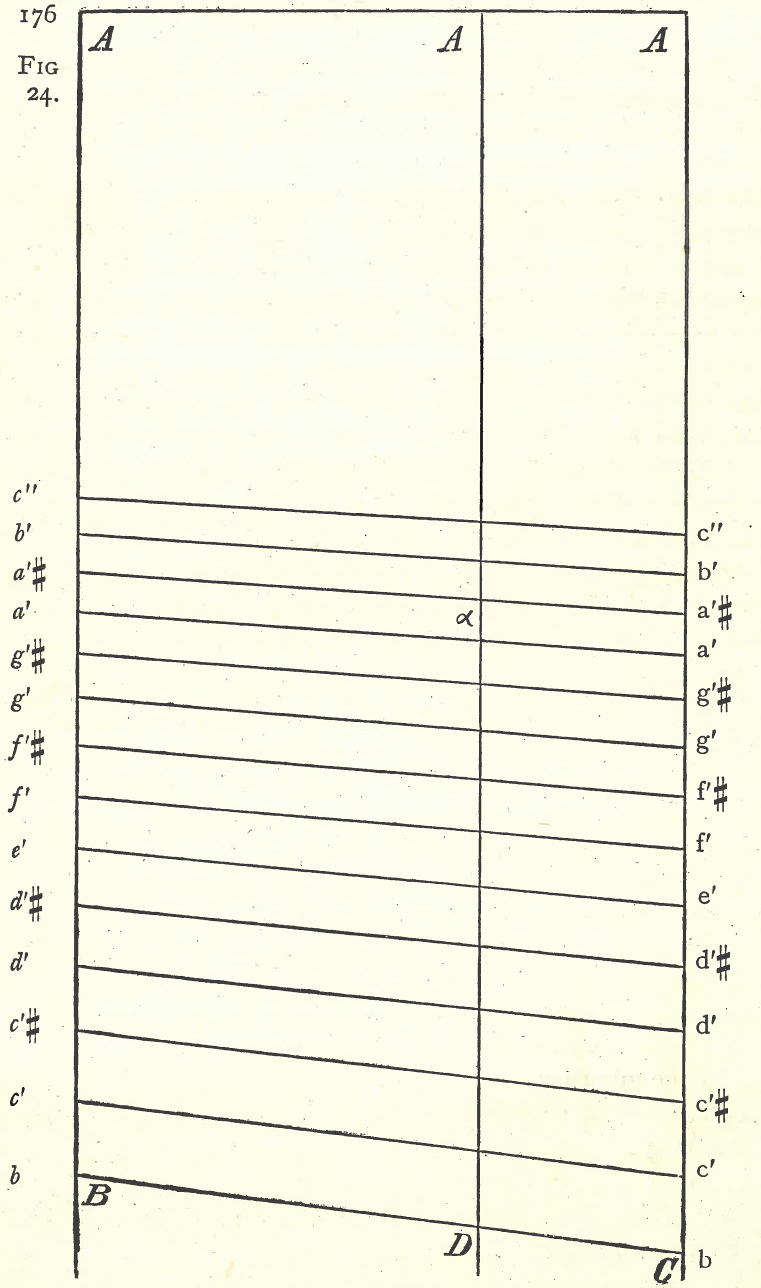
For a scale adapted to any intermediate pitch, find by experiment the distance, from the mouth-hole centre, of any finger-hole giving a note of the desired pitch; mark the position for that hole on the corresponding line (as, for instance, *a* on the line *a′* a′), and draw a straight line through the point *A* and the point *a* to *D*. The points of intersection will give the required scale on *A D*.

Should it be desired to form a scale higher or lower than any contained between *A B* and *A C*, it will be obvious that it may be obtained by producing the lines *c″* c″, etc., to the necessary distances.

353. The lines *A B*, *A C* and *A D* may be drawn parallel to each other, as shown in *fig.* 24, if so preferred, but in that case the scale *A C* must be taken by measurement from the scale *A B*. The distance *b′ a′*♯ on *A B*, will give the distance c″ b′ on *A C*, and so on in like manner.

If the vibration number of the note intended as the foundation of the new scale be known (as, for instance, of *a′*), the oblique line *a′* a′, in *fig.* 23 or *fig.* 24, may be converted into a scale corresponding to the vibration numbers between 452 (*a′*) and 426.63 (a′). Then the required positions may be found without further experiment.

Fig 24.



354. The positions of the finger-holes for a conoidal flute may be calculated from the same data as those for a cylindrical one, but the ratio of increase in the spaces between the holes will be found to be not only directly proportional to their distance from the mouth-hole, but also inversely proportional to the angle formed by the sides of the tube.

Great accuracy is necessary in constructing a trustworthy scale, and it is an exceedingly tedious and delicate operation, as the smallest error will of course falsify every succeeding measurement. The instrument used for this purpose should be furnished with a micrometer screw. The above diagrams are only intended to illustrate the best methods of setting out scales. It will scarcely be thought possible that they could be sufficiently accurate to admit of their being used as models. The figures in §351 are the only sure guide.

In setting out the centres of the finger-holes on a flute, it is customary for the workman to measure from one fixed point, so that any slight errors that may occur shall not be accumulated.

355. An excellent practical test of the accuracy of the tuning of a flute, is the comparison of the harmonic *octaves* and *twelfths*. If these agree sufficiently nearly for the requirements of equal temperament, the intonation may be pronounced perfect, but not otherwise. Considerable experience and skill are necessary for the successful application of this test.

The flutes manufactured by Boehm fail signally under this rigorous ordeal. The notes of his flutes become too flat, in an irregular kind of progression, as the distance of the finger-holes from the mouth-hole increases. According to his *schema* (1868) the tuning would have erred in a contrary direction.

Any variation in the thickness of that part of the tube in which the finger-holes are placed, would, of course, falsify all calculations, not only because extra thickness, *per se*, causes extra flatness, but also because of the resulting increase or diminution in the length of the small tubes formed by the walls of the openings; each of these small tubes constituting an addition to the length of the main column of air.

356. It is shown, in §325, that the tuning of a flute can be theoretically perfect at one pitch only, therefore the scale given for the pitch corresponding to *a'*, with 452 vibrations, is strictly adapted for that pitch and for no other, but practically it will admit of a certain amount of alteration by the tuning slide without any further departure from truth than can be easily corrected in playing. The limit of alteration should not, however, exceed $\frac{1}{8}$th of an inch either way. To allow of its being sharpened to this extent, a flute must be made so much shorter than the requisite length for the above-named pitch; then, when the slide is pushed closely in, the average pitch of the instrument will correspond to *a'* with 455 vibrations, and when it is drawn out $\frac{1}{4}$ of an inch, the average pitch will correspond to *a'* with 449 vibrations.

357. *Vent-holes.* A good flute-player may succeed in producing three octaves of notes from his instrument without the assistance of vent-holes, (see §§149 to 153) but, no matter how skilful he may be, the third octave, thus unaided, will be uncertain, unmanageable, and extremely unpleasant in quality of tone; moreover, unless considerable force of breath be applied, the notes will be too flat in comparison with those of the first and second octaves.

The disagreeable tone of the harmonic *twelfths* and *fifteenths*, when unassisted by the opening of vent-holes, is mainly due to the presence of the lower attendant sounds described in §§192, 193 and 228. The prominence of these objectionable sounds is in direct proportion to the number of segments into which the column of air is divided, and also to the length of the column.

In order to remedy these grave defects, the use of vent-holes for the third octave is indispensable, and it has always been the custom to employ them for that purpose, for, if rightly situated and of the proper size, they effectually prevent the occurrence of the lower attendant sounds, and compelling, as they do when correctly placed, the nodes to take up the required positions, they render the notes easy to produce; they

cause the tone to be clear and flexible, and at the same time they bring the pitch of the third octave into true relationship with that of the first and second octaves.

The reason why the natural harmonics, above the octaves, are so defective is that the bore of the flute cannot, at the same time, perfectly suit the fundamental sounds and more than the first series of harmonics. If large enough for all these, it will be too large for the higher unassisted harmonics. The converse of this proposition is equally true.

The proper vent-holes for the notes of the third octave, from *d'''*♯ to *g'''* inclusive, are the note-holes of the *twelfths* below, namely, *g'*♯ to *c''*, which note-holes would, of course, be capable of giving imperfectly the higher sounds as their second harmonics. The uses of the *c''*♯ hole as a vent-hole are explained in §360.

358. Every vent-hole should be large enough to prevent, as far as possible, the presence of the lower attendant sounds, but not so large as to interfere with the certainty of its action as a vent-hole. The diameter of .64 inch, already given as the most advantageous for note-holes, is also the best adapted for vent-holes, as the positions of the vent-holes should coincide with the positions of the antinodes, and this end can only be attained by the adoption of holes of the size above named; hence equality of diameter becomes a paramount necessity. Gradually reducing the sizes of the holes, as they approach the mouth-hole, necessitates the lessening of their distance from this opening; in that case the vent-holes will be above the true antinodes, and excessive sharpness of the pitch of the third octave will be the inevitable result. The effect of difference of size in note-holes, on the pitch of the notes, is about three times as great as in vent-holes.

Taking all these indisputable facts into consideration, it must be not only obvious that the position of a vent-hole is of more importance than its size, but also that the position of a vent-hole is of infinitely more consequence than the position of a note-hole. The greatest advantage accruing from the "cylinder' bore is the opportunity that it affords for placing the vent-holes in their true positions, by rendering possible the use of larger holes than could be employed in a "conical flute" consistently with uniformity in their diameter.

359. The explanation, on theoretical grounds, of the complicated and obscure subject of the foregoing section, is most difficult, as the whole question is involved with those uncertain elements, the portions of the column of air that extend beyond the mouth-hole and the note-hole. Experimental proof of the facts above stated may, however, be easily obtained in the following manner:

Take a flute, such as is described in §§679-683, and finger *g'*♯. Open a sufficient portion of the perforation in the key of the *b*♭ hole to give a true *a'* when that key and also the key of the *a'* hole are closed, the *g''*♯ hole, and all below it, being open. The partial closing of the perforation in the key may be conveniently effected by inserting a piece of cork, and boring in this a hole of the requisite size. We shall then have two alternative *a'* holes of different sizes, the smaller one .826 inch above the larger one, and both giving the same sound, as regards pitch, notwithstanding their difference of position. In this case the difference of diameter evidently affords adequate compensation, as far as pitch is concerned.

Now, test the difference of pitch caused by the alternative use of these two holes as vent-holes for *e'''* (this note being taken as the harmonic double octave of *e'*), and the harmonic determined by the higher vent-hole will be found to be at least twenty vibrations in a second above that determined by the lower hole. In this case it is evident that the difference in the diameter of the vent-holes does not afford adequate compensation for the difference in their position.

360. *The c''♯ Hole* may be considered as the *bête-noire* of the flute: it has so many duties to perform, besides that of giving its own particular note, which are theoretically quite incompatible with any one of its possible positions, that a judicious compromise is all that can be effected. See §345.

The enumeration of the functions of this aperture may be startling, but the difficulty must be met, and it is therefore desirable that we should see it in its true proportions. The subjoined table will show the numerous purposes which this overtaxed opening has to serve. The reason that the special *c''*♯ (see table) and the ordinary *d''*♮ and *d''*♯ require a vent-hole is that the bore in general use is slightly too large for them. If the bore were smaller, these three notes would sound more clearly and more readily, but, as before stated, the lower notes would not be so good. Another, and more powerful cause of the difficulty, in the unassisted production of the three notes above mentioned, is the length of the tube employed in their formation, which gives rise to a severe tax on the lips of the performer in effecting the necessary divisions. It is impossible to produce, as unassisted harmonics, *c''*♯ and *d''* with an agreeable tone, the lower attendant sounds being exceedingly prominent when the notes are thus fingered.

Table of the Uses of the c''♯ Hole.

I.	A note-hole for - - - - -	*c''*♯
II.	A vent-hole for a special fingering of - -	*c''*♯
III.	A vent-hole for - - - - -	*d''*
IV.	A vent-hole for - - - - -	*d''*♯
V.	A note-hole for - - - - -	*c'''*♯
VI.	A vent-hole for four special fingerings of - -	*c'''*♯
VII.	A vent-hole for two fingerings of - - -	*d'''*
VIII.	A vent-hole for a special fingering of - -	*d'''*♯
IX.	A vent-hole for a special fingering of - -	*e'''*
X.	A vent-hole for nine fingerings of - - -	*g'''*♯
XI.	A vent-hole for six fingerings of - - -	*a'''*
XII.	A vent-hole for two fingerings of - - -	*a'''*♯
XIII.	A vent-hole for - - - - -	*c''''*♯
XIV.	A vent-hole for - - - - -	*d''''*

361. Ideal perfection in all the thirty-two notes of the above table (and even these do not quite exhaust the catalogue) could only be secured by at least five alternative apertures, but the idea of making a flute with such an addition to the usual number of holes is simply Utopian. The complication of machinery that would be necessary to bring them into play is out of the question, on an instrument intended for general use, it is therefore unnecessary to calculate their sizes and positions. The usual custom is to give the $c''\sharp$ hole an approximate diameter of .28 inch, and to place it at a distance of about 1.26 inch above the $c''\natural$ hole. This is a fair compromise, for such a hole, thus placed, answers surprisingly well for its multifarious uses, and happily the large $c''\natural$ hole exercises so beneficial an influence on the tone of the $c''\sharp$, that in practice little fault can be found with the last mentioned note, notwithstanding the smallness of the opening from which it is produced: see §147. Boehm used to place the $c''\sharp$ hole so high, for the sake of improving its action as a vent-hole, that he completely ruined the tone of the fundamental note. In the year 1873 he added an extra vent-hole, above the $c''\sharp$ hole, but as this required to be governed by a closed key which had to be opened by the left hand thumb, at the same time that the usual thumb-key was pressed down, it was of very little use.

362. In 1877 I somewhat improved the influence of the $c''\sharp$ hole, when used as a vent-hole for certain notes, by a modification of a contrivance that Cornelius Ward had applied to a flute for which he obtained a patent in 1842. Instead of the usual hole, Ward made use of two, the lower one being much the smaller, and both were opened or closed together. He thus specifies the supposed result of this change : "The effect of this arrangement is to improve the tone and tune of the notes D natural and E flat" (1842). This plan could scarcely be called an improvement, as it injured the $c''\sharp$ without materially benefitting any other note. I reversed the positions of these two holes, placing the smaller one above the larger, and, in consequence of this alteration, the ordinary fingerings for $d''\sharp$,

$d'''\natural$ and a''' gave better notes, the $d''\sharp$ being rendered firmer, its previous tendency to "crack," (particularly when the flute was drawn out) being removed, while the $d'''\natural$ and the a''', which had been rather too flat, were raised to their correct pitch. Besides the improvement of these three ordinary notes, collateral advantages were obtained in certain special fingerings for $d'''\sharp$, e''', a''', etc. A slight deterioration in the power of the tone of the $c''\sharp$ was caused by the lessening of the principal hole, which was rendered necessary by the addition of the smaller one, but this deterioration was not serious. The sizes and positions of these two holes, tuned in accordance with a' 452, were as follows :

	Diameter.	Distance above c'' hole.
Upper hole, -	.11 inch - -	1.659 inch.
Lower hole, -	.25 „ - -	1.209 „

In 1882 I invented a contrivance for two alternative $c''\sharp$ holes, but I have never had it applied to a flute for three reasons : it is really hardly necessary ; it would cause serious complication of the machinery, and the expense entailed would probably prevent its general adoption. Whether I shall ever think it worth while to make any use of this scheme is more than doubtful.

363. *The latest Improvement in the $c''\sharp$ Hole.* In September 1889 I completed a contrivance which is perfectly automatic in its action, for the improvement, more or less, of all the notes influenced by the $c''\sharp$ hole. The improvement is effected by the addition of a small tube placed at right angles to the flute. This tube, which is .36 inch in length, forms the $c''\sharp$ hole. The centre of the $c''\sharp$ hole is 1.36 inch from the centre of the $c''\natural$ hole, and its diameter is .33 inch. The interior of the tube is perfectly cylindrical. The exterior orifice of the tube is the true note-hole, therefore, as is the case with all note-holes, when the aperture is utilized, the main column of air is lengthened by the addition of the smaller column contained within the walls of the finger-hole: see §355. It will be at once seen that the increased distance of the note-hole from the mouth-hole would permit the employment of a larger opening than would be otherwise possible without the undue raising of the pitch of the $c''\sharp$. It will be equally obvious that the increased diameter of the $c''\sharp$ hole would be the cause of a fuller tone. As a matter of fact, the tone of the $c''\sharp$, produced from a hole of the above-mentioned diameter, is equal to that of the $c''\natural$ from a hole of .64 inch, and a $c''\sharp$ hole of a greater diameter than .33 could not be employed with advantage (see §§147 and 345), on account of the coarseness of tone that would be induced by so large an opening in such a high position.

The interior orifice of this added tube forms in reality the vent-hole; this, in consequence of the length of the tube, is practically .36 inch higher than the note-hole formed by the exterior orifice. It is very nearly at the antinode of $d''\natural$, (taken as the first harmonic of $d'\natural$) but, as is well exemplified by the "speaker" of the clarionet, the application of the tube enables the opening to be used with advantage in the determination of the antinodes of several more notes than it would be practicable so to determine without it. As an instance: the shake d''—e'' may be made perfectly well with the hole open. An account of the further advantages of this new contrivance will be found in §796.

364. *Tendency of Vent-holes to cause undue Sharpness of Pitch.* Even with the best system of construction, and the most judicious arrangement of the finger-holes, we are met by a difficulty due to the pressure of the lips which is necessary for the production of some of the notes above f''': this unavoidable pressure is apt to cause the notes in question to become too sharp. I have resorted to various contrivances for the removal of this evil, which are completely successful and which have no corresponding disadvantages. The details of these contrivances will be found under their respective heads, *Machinery* and *Fingering*.

365. *The Supernumerary $d''\natural$ and $d''\sharp$ Holes.* In order to facilitate the execution of certain passages, and to render certain shakes possible, several holes have from time to time been placed above the $c''\sharp$ hole. Flutes of modern type are generally provided with two such holes, one for $d''\natural$ and the other for $d''\sharp$. For the first we are indebted to J. Nepomuk Capeller of Munich, 1811; for the second to Victor J. B. Côche of the Paris *Conservatoire*, 1838. The $d''\natural$ hole alone gave many exceedingly imperfect notes, some of them false to the extent of a quarter of a tone. The $d''\sharp$ hole would have been of little use without the other, though it was a most valuable addition, for it not only facilitated numerous passages and shakes, but, by its occasional substitution for the $d''\natural$ hole, the worst defects in the action of the latter were removed, and whereas the $d''\natural$ could only receive slight occasional assistance from the small $c''\sharp$ hole, the $d''\natural$ hole could be employed, whenever occasion required, to improve the $d''\sharp$. Further information on the subject of the supernumerary holes will be found in subsequent chapters.

Notwithstanding Côche's improvement, the use of these holes was much circumscribed, and in 1850 my friend, Mr. Carte senior, introduced an "open d''" which is attended with great advantages, as far as the note itself is concerned, but which gives rise to the necessity for changes in the fingering of the $c''\sharp$. The further particulars of this ingenious invention will be found in chapters XV. and XIX.

366. The increase of the size of the finger-holes, in 1864, was extended in some degree to the d'' and $d''\sharp$ holes, with excellent results. In 1877 I effected a considerable further improvement by utilizing the principle described in §147. A hole, with the usual diameter of .64 inch, is pierced about midway between the $d''\natural$ and $c''\natural$ holes, the exact position is unimportant. This extra opening is connected inseparably with the usual $d''\natural$ hole, and it confers such ample power on the d'' that this note is quite equal in strength to any of the others, and the $d\sharp$ of the hole above, being always assisted by the opening of the two holes below, is much improved. The numerous benefits derived from this extra hole will be found described in their proper places; for the present it will be sufficient to say that most of the advantages of the "open *d''*" are secured without any change in the general fingering being involved.

---

367. Excepting for the purposes of causing the several octaves to agree with each other in pitch, and making the requisite compensation for the effect of change in the force of the breath, a flute with its tube constructed on the principles advocated above, will require no alteration in the direction of the air-reed, (that is to say, its intonation will be perfectly true, according to the system of equal temperament, unless it be rendered false by unskilful blowing) provided always that opportunities are afforded for reaping the full advantages of the system of construction. These required opportunities form the subject of the next chapter.

CHAPTER XII.

ON THE FINGERING AND THE MACHINERY OF THE FLUTE.

§368. THE FINGERING.—372. *DUPLICATE NOTE-HOLES.*—373. *CROSS-FINGERING.*—378. *ADVANTAGES OF THE CONSTANT EMPLOYMENT OF ALL THE FINGERS.*—379. THE MACHINERY.—380. *THE KEYS AND THEIR SUPPORTS.*—383. *THE FLAPS, LEATHERS, PLUGS, CUPS, PADS AND BEDS OF THE KEYS.*—388. *THE RISE OF THE KEYS. STOPS.*—389. *THE SPRINGS.*—391. *PERFORATIONS IN THE KEYS, ETC.*—394. *"OPEN" AND "CLOSED" SYSTEMS OF KEYS.*—395. *LEVERS AND THEIR CONNECTIONS.*—396. *THE CRUTCH.*

368. The Fingering of the Flute. The opening or closing of the finger-holes of any wind-instrument is technically called the *fingering*, and the separate or combined action of the fingers in determining a particular note is called the fingering of that note. It must be obvious that unless a rational system of fingering be adopted, excellence in the material and the construction of the tube can be of no avail. It therefore becomes a paramount necessity that means should be provided for readily opening and closing the finger-holes, either separately or in any desirable combinations.

The historical account of the fingering of the various kinds of flutes will be found in chapters XIII. to XV., we have at present to deal with the principles that should govern the fingering in order that the full advantages of scientific construction may be obtained, neither intonation nor quality of tone being allowed to suffer by the closing of holes that ought to be open, and the consequent improper veiling and flattening of the notes. Compared to these important considerations, facilities