Again, reeds are distinguished as free or striking reeds. *A* and *B* (Fig. 101) show in perspective and in section a free reed such as is used in harmoniums. As you will remark, the reed *z z*, which is technically called a tongue, or vibrator, is attached to a metal block, *a a*, in which there is an opening a trifle larger than the tongue. When at rest, it occupies the position shown in *A*. When in motion the tongue occupies alternately the positions shown at z_1 and z_2 *B*. In the former position there is an opening for the admission of the air, as indicated by the direction of the arrow. In the latter, the stream of air is cut off entirely, when, in virtue of the elasticity of the tongue, it returns to its former position, z_1.

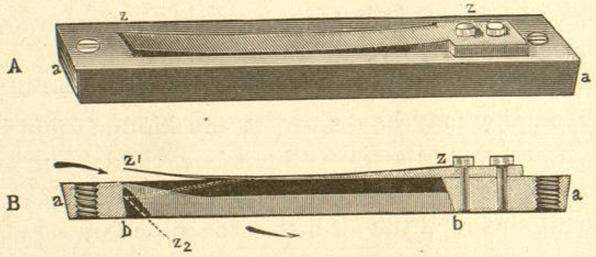

FIG. 101.

From the foregoing it appears that the action of a reed is essentially the same as that of a siren. The principal difference lies in the manner in which the orifice which admits the air is opened and closed. In the siren this is effected by the rotation of a delicately balanced disk. In the reed it is accomplished by the oscillatory movement of the tongue. The function of the reed is purely mechanical. It merely serves the purpose of determining the period of vibration of the air, which is itself the sonorous body, and not the reed, as is sometimes supposed.

A and *B* (Fig. 102) show the kinds of reeds used in connection with organ-pipes. In the former is a free, and in the latter a striking reed. The length of the tongue, and consequently its pitch, is in both cases adjusted by a movable wire, *d*, called a tuning-wire. The note of *A* is reinforced and its quality modified by a conical tube.[1] The wind is driven into an air-chamber, *p p*. Thence it passes into the semi-cylindrical tube, *r r*, fastened to the block, *s s*. The

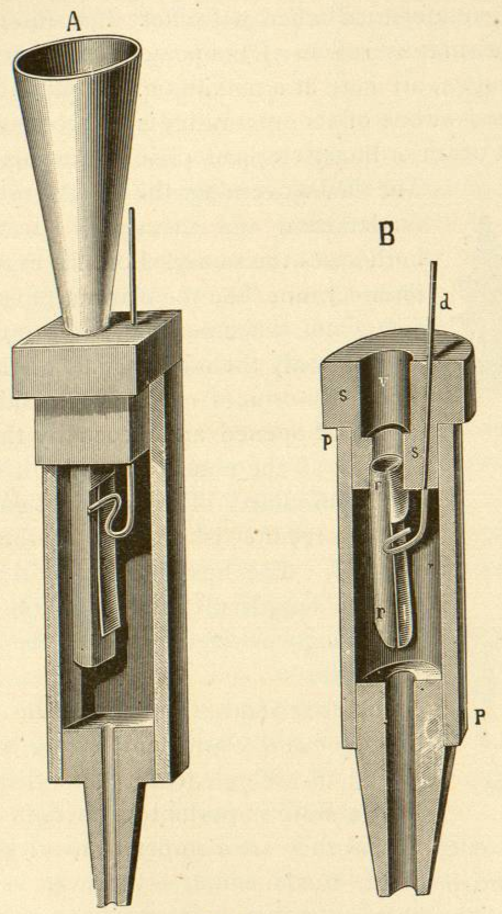

FIG. 102.

tongue is thus caused to execute a series of oscillations which determine the pitch of the vibrating air-column. Pushing down the tuning-wire would, as is obvious, shorten

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[1] In organs, the reed-pipes are made to yield notes of different qualities according to the form and length of conical and pyramidal pipes, — "cornets," — with which they are connected.

the tongue, and consequently heighten the pitch. Raising the wire would lengthen the tongue and lower the pitch.

Helmholtz has demonstrated that the point of a pipe at which a reed is inserted is to be considered a node. This is readily understood when we reflect that the variations of air-pressure, by reason of the peculiar vibratory motion of the tongue, are here at a maximum. A pipe, therefore, with a reed at one of its extremities is to be considered in the light of an ordinary stopped pipe of the same length.

FIG. 103.

The law governing the production of the fundamental and the upper partials is in both cases the same. For this reason a cylindrical tube, like the clarinet (Fig. 103), is competent, when emitting its proper notes, to yield only the odd partials of the prime tone. By orifices made in the side of the tube, and opened and closed by the fingers or keys, all the notes of the chromatic scale may be obtained. The annexed figure shows how the reed, *C*, is attached to the mouthpiece, *B*. The lips of the performer regulate the length of the reed here, as does the tuning-wire in the case of the ordinary reed-pipe.

The oboe and bassoon, as has been stated, differ from the clarinet in having a double, instead of a single, reed. But there is, besides, a more important distinction. Owing to their conical form,[1] they are competent to yield all the upper partials of the fundamental, — the even as well as the odd. The bassoon differs from the oboe in that the tube of the latter is of greater volume than that of the former. The lowest note of the bassoon is a twelfth below the gravest tone of the oboe. For this reason the bassoon is to the oboe what the violoncello is to the violin.

In the heavy metal tongues of the harmonium and the organ, the notes emitted have sensibly the same pitch as would be yielded by the isolated vibrating tongues. There must, therefore, in these cases be at least one tongue for each note.

The lighter reed-tongues of the clarinet, oboe, and bassoon, on the other hand, are capable of yielding a large number of notes. The reason is that the vibrating column of air in these instruments has sufficient force to control the vibration of the tongue, and compel it to yield notes corresponding in pitch to the proper notes of the tube. As a consequence, the tongue is made to execute vibrations whose period is much greater than those which it would make if isolated. As a matter of fact, the proper notes of the tongue are never used in music, because they are too high and piercing, and because it is impossible to give to them any degree of steadiness.

FIG. 104.

Instruments like the French-horn, cornet, ophicleide, and other brass instruments of this class, differ from those of which we have been speaking, not only in their form and in the quality of the tone that characterizes them, but especially in the form of mouthpiece employed. As is seen from those I have in my hand (Fig. 104), they are conical, or cup-like, in shape. Such mouthpieces are known as *embouchures de cor*, or horn mouthpieces. Connected with resonant tubes, they are applied to the lips, which then act just as reeds. The air from the lungs sets the lips in vibration, and with them the column of air in the instrument. The rapidity of oscillation depends on the pressure of the air and the tension of the lips, or the force with which the performer presses them against the embouchure. It is the proper adjustment of the wind pressure and the tension of the lips that make playing on these instruments so difficult.

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[1] Mr. Ellis says, "Too much has been attributed to the cylindrical bore for producing only the unevenly numbered partials." He quotes Mr. Hermann Smith, who, having given the subject special study, states that "an oboe reed fixed on the clarinet tube gives oboe pitch of tone and oboe partials" (Ellis's Helmholtz, p. 553).

According to Mr. D. J. Blaikley, quoted by Ellis, "the lips do not vibrate throughout their whole length, but only through a certain length, determined by the diameter of the cup of the mouthpiece. Probably also the vibrating length can be modified by the mere pinch, — at least this is the sensation I experience when sounding high notes on a large mouthpiece. The compass — about four octaves — possible on a given mouthpiece is greater than that of any one register of the voice, and the whole range of brass instruments played thus with the lips is about one octave greater than the whole range of the human voice, from basso profundo to the highest soprano."

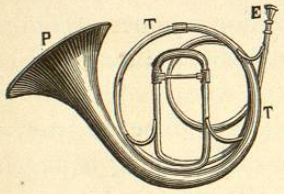

Fig. 105.

Before you (Fig. 105) is one of the older forms of the French-horn, which corresponds to the Waldhorn, or German hunting-horn. As you see, it is a long coiled conical brass tube, *E T T*, terminating in a wide "bell," *P*. As it has no side-holes, or keys, it can yield only its prime and the corresponding harmonic upper partials. According to Zamminer, the tube of such a horn is 13.4 feet long. Its fundamental note is $E\flat_{-1}$. This, and the first upper partial $E\flat_1$, are never used. Only the higher partials are employed in music. These, beginning with the third partial, are $B\flat_1$, $E\flat_2$, G_2, $B\flat_2$, $D\flat_{3-}$, E, F_3, $A\flat_{3+}$, $B\flat_3$, etc., and supply most of the tones of the scale. Those which are missing are partially elicited by placing the closed hand in the bell of the horn, thus more or less closing it at this point. For this reason such notes are sometimes called "hand-notes."

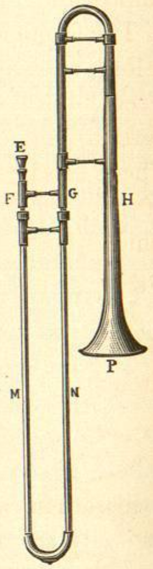

Fig. 106.

The trombone (Fig. 106) is a modified form of the horn. It is composed of a fixed part, *E F G H P*, and a movable part, *M N*, by means of which the player can vary the length of the aërial column, and thus, also, the pitch of the notes emitted.

The trumpet belongs to the same class as the trombone; indeed, the latter is the natural bass of the former. The trumpet speaks in an octave higher than the French-horn, of which it possesses the first eleven open notes. On all these instruments, owing to the absence of fixed notes, it is possible, as with instruments of the violin family, to play in pure intonation. For this reason, they are capable, in the hands of expert players, of yielding musical effects that, with keyed instruments, are quite impossible.

The ophicleide, *E P* (Fig. 107), is also a long conical tube, but it differs from the French-horn and the trombone in having a certain number of openings along its side. These can be closed and opened by means of keys, and thus the number of notes which the instrument is capable of yielding is greatly augmented.

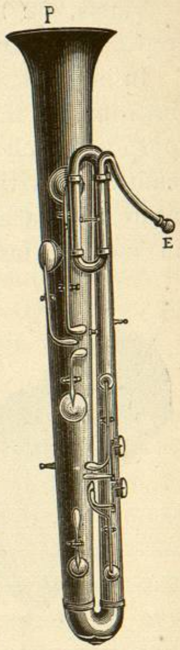

Fig. 107.

The cornet-a-piston (Fig. 108) is an improved form of the trombone, just as the trombone is a modification of the French-horn. Like its prototypes, the cornet-a-piston is provided with a bell, *P*, and an embouchure, *E*. Parallel to the principal tube of the instrument are placed smaller tubes, *B*, *C*, *D*. These latter are put into communication with the former by means of the cylinders, *M*, *N*, *P*, in which pistons connected with the rods, *m*, *n*, *p*, are made to open valves. This is equivalent to lengthening the tube so as to make

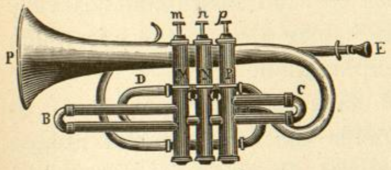

Fig. 108.

it yield notes one, two, or three semitones flatter. The valve-action in the cornet thus serves the same purpose as the sliding-tube in the trombone. These instruments, like clarinets, are made of various sizes and pitches, and are especially employed in military bands.

In instruments like the flute, clarinet, and similar keyed instruments, the acoustic length of the tube — that is, the portion which chiefly determines the pitch of the note emitted — is that part between the embouchure and the nearest open aperture. Opening or closing the six holes in such an instrument is tantamount to lengthening or shortening the tube, and, consequently, to raising or lowering the pitch of the notes emitted. In brass wind instruments, on the contrary, the acoustic length of the tube is, as we have seen, more generally regulated by valves and sliding-tubes, which determine the length of the aërial column actually in vibration. It would, however, be a misstatement of fact to say that the opening of the side-holes of wind instruments has precisely the same effect as shortening the tube. Such is not the case; and for the simple reason that the reflection of the sonorous pulses from such lateral opening is not exactly the same as that at the open end of the instrument. The theory of the side-holes of wind instruments is very complicated, and strange as it may appear, there is much about it that still requires explanation.

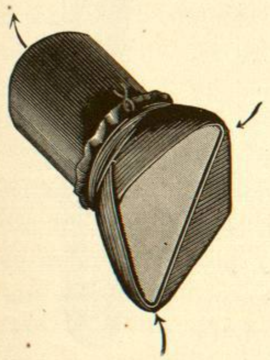

Fig. 109.

In the human larynx we have the most perfect of all musical instruments. It yields the sweetest and richest tones, and admits of variations of pitch, intensity, and quality that in other instruments are quite impossible.

A model of the larynx in its simplest form is shown in Fig. 109. This is a modified form of that first devised by the illustrious comparative anatomist, Johann Müller. It is nothing more than a short glass tube, across one of the ends of which are stretched two bands of india-rubber so as to form a narrow slit through which air may be urged. When in vibration each of the strips of rubber acts as a reed, and as there are two of them, this simple device is nothing more than a double-reed instrument.

The same may be said of the organ of the voice; it is nothing more than a double-reed instrument. The trachea, or windpipe, corresponds to the glass tube in the model in my hand, and the vocal cords to the strips of india-rubber.

The vocal cords are caused to vibrate by air issuing from the lungs, and the variations in the pitch of the notes emitted are determined by modifications in the tension and length of the cords, as well as by the length and width of the intervening aperture called the glottis.

The quality of the tone depends partly on the structure of the larynx itself, and on the form and size of the vocal cords, and partly on the form and size of the oral and nasal cavities, which perform the office of resonators. As all parts of the larynx, and its adjoining resonant cavities, are perfectly and readily adjustable, we have in the organ of the voice an instrument that is susceptible of every shade of modulation, and of the most marvellous variations of quality and power.

So far we have been speaking of sonorous tubes which are set in vibration by a blast of air from a bellows, or that which serves the same purpose, the lungs. The air-columns of tubes may, however, be excited by other means. Anything competent to impart a periodic impulse to the air within a tube, is sufficient to cause the generation of a musical note.

A jet of ignited gas may, under suitable circumstances, give rise to a loud, pure tone. A simple means of illustrating this fact, as we saw in our first lecture (Fig. 10), is afforded by the chemical harmonicon. The apparatus used consists, as you remember, of a Woulfe bottle, in which are placed the materials for generating hydrogen gas. In one of the openings of the flask is fixed a safety tube, and in the other a small glass tube drawn to a fine point, through which the hydrogen issues. On igniting the gas, and holding over the flame a glass tube of suitable size, you at once hear a clear, musical note.

Faraday was the first to demonstrate that the note is due to a series of rhythmic explosions whose periods synchronize with the rate of vibration of the aërial column enclosed by the tube. Chladni showed that the glass tube in this case acts exactly like an open organ-pipe, and that by properly adjusting the size of the flame and its position in the tube, one can not only get a note corresponding to the fundamental of the pipe, but also elicit at least two of its upper partials.

With a larger apparatus than the one just used we evoke much louder tones and a greater number of partials than were obtained by Chladni. We have here a large copper cylinder, in which hydrogen is condensed under high pressure. Near by is a number of glass tubes of various sizes, from two to six feet in length, and from one to two inches in diameter. Among these are eight which are of the same diameter, but whose lengths are so adjusted that they give, when placed in succession over the flame, the eight notes of the diatonic scale. Measuring the length of these tubes, we find that they are inversely as the pitch of the notes they respectively emit. They therefore conform to the same law as the other forms of sonorous tubes which we have been investigating.

Taking one of the larger tubes, and holding it over a larger flame, we get a louder and deeper note than any we have yet heard. The tube is now yielding its prime tone. Lowering the flame, a note of higher pitch is heard. This is the octave of the fundamental. Diminishing still more the size of the flame, we obtain the twelfth, or the third partial. In a similar manner, by regulating the size of the flame and its position in the tube, we should be able to elicit a number of higher partials.

It has been said that the notes produced by such flames are due to a series of explosions. Wheatstone has shown us how we can prove this experimentally. Taking the cubical mirror, which we have used in studying Koenig's manometric flames, and rotating it before the singing flame, we see that it is immediately resolved into a chaplet of luminous images. The images are at a greater or less distance from each other according to the greater or less velocity of rotation of the mirror. Reducing the flame to silence, we have reflected from the mirror a continuous band of light. The band remains continuous as long as the flame is in a state of quiescence. But as soon as it is made to sing, the ribbon of light seen in the mirror becomes discontinuous as before.

It is an easy matter to determine the number of explosions per second corresponding to the note which is being produced. All that is necessary is to obtain the pitch of the note. This can be done approximately by measuring the length of the sonorous tube, and dividing this length, multiplied by 4, into the velocity of sound per second. It would obviously be necessary in this case, in order to have anything approaching an exact result, to make corrections for the high temperature of the aërial column, and for the amount of aqueous vapor present. We can, however, estimate approximately the pitch of the note by ear. But our tuning-fork tonometer stands us in good stead now. A few trials will enable us to determine almost exactly the pitch of the note now sounding. We find that it approximates closely that of the fork I now hold in my hand, F_3, which executes 348 vibrations per second. As, therefore, each explosion is equivalent to a single vibration, we conclude that the tone of the flame now singing is produced by a series of rhythmic explosions which number about 350 per second.

Instead of using glass tubes, let us take this brass tube supported on a solid stand. The tube is over three inches in diameter, and about eight feet long. And instead of the small jet hitherto employed, we shall use that issuing from a large rose burner. The gas is now ignited, and placed in position within the tube. Regulating the pres-