

paper [taken from *Engineering*, London, Oct. 27, 1876] by Mr. Sabine, giving the details of a series of experiments; to this paper I refer my hearers; and for a more complete description of Mr. Sabine's methods, a reference to the original paper in the *Philosophical Magazine* for May, 1876, will be advisable.

## TONOMETRY.

By A. J. ELLIS.

[From the *Athenæum*, London, December 2d, 1876.]

The Problem of Tonometry is: given a sustained musical tone to determine the number of vibrations made in one second of time by each particle of air, conveying the undulation to which the sensation of sound is due. By a vibration in France is meant the motion from the extreme position on one side, to the extreme on the other, like the single swing of a pendulum. In England, and now in Germany, by a vibration is meant the motion from the extreme position on one side, to the return to the same position, like two swings of a pendulum. *This* will here be always understood by the term vibration, and the former will, when necessary, be distinguished as a simple vibration. Tones are simple when the motion of the air follows the law of a pendulum; and compound in other cases. Compound tones are heard as if a certain number of simple tones (called partials) were sounded simultaneously. In this case the pitch is the number of vibrations made in one second by the lowest partial.

The old attempts at tonometry were made by a monochord, which was horizontal, or, much better, vertical,<sup>1</sup> stretched by a weight mathematically determined by the transverse section and specific gravity of the string, and limited by a fixed bridge at one end, and a movable bridge at the other. The pitch could then be calculated from the measured length of the string. More recently the siren, in which a perforated plate was driven by a stream of air with increasing, but constantly measured velocity, producing a constantly higher note, has been extensively used. The pitch of the given note had

<sup>1</sup> Smith's "Harmonics," and General T. Perronet Thompson's "Just Intonation."

to be determined by the estimation of the ear as to when the monochord or siren gave a note identical with that under examination. All these methods are liable to numerous errors, and practically their results cannot be depended on to 10 vibrations in one second. Other methods were still worse.

Tonometry was first placed on a scientific basis in a badly written, but extremely valuable, little pamphlet of 80 pages and 4 lithographic plates, published at Essen, 1834. This pamphlet was entitled "The Physical and Musical Tonometer (*Tonmesser*), which proves by the pendulum, visibly to the eye, the absolute vibrations of tones, and of the principal general of combinational tones, as well as the most definite exactness of equally tempered and mathematical chords, invented and executed by Heinrich Scheibler, silk-ware manufacturer in Crefeld." [Crefeld is a town of Rhenish Prussia, twelve miles north-west of Düsseldorf, celebrated for its silk factories.] The principle upon which Scheibler proceeded was this. Tones which differ by a small amount "beat" together,—a very familiar phenomenon—varying from a slow wave to a rapid rattle; and the number of beats in a second is precisely the same as the difference in the numbers of vibrations which the two tones make in a second. A tuning-fork will also beat with an imperfect octave above it, and then the number of beats is the difference between the number of vibrations of the upper tone, and double the number of vibrations of the lower tone. Thus 256 and 259, or 256 and 253, beat three times in a second; and 256 and 515, or 256 and 509, also beat three; that is, the beats do not show whether the upper note is too sharp or too flat. This has to be ascertained by flattening the upper tone (placing the upper tuning-fork under one's arm for a minute or two is sufficient); if then the beats diminish in number, the upper note is brought more in tune, and was too sharp; if the beats increase in number, the upper note is brought more out of tune, and was too flat. For compound tones, other intervals can be selected, as shown below.<sup>i</sup> Then two forks being tuned roughly to (say) A on the first line on the bass staff, and

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<sup>i</sup> Let the ratio of any perfect interval be  $m : n$ ,  $n$  being the greater number. Let two compound tones, having the vibrations  $y$  and  $z$ , and audibly possessing the  $n$ th and  $m$ th partials respectively, form exactly this interval, then  $m : n :: y : z$ , or  $mz = ny$ , and no wave is heard. If they do not exactly form the interval, the difference of  $mz$  and  $ny$  gives the number of "beats of error," as distinguished from the "rattle of the beating partials," which always exists more or less distinctly in "reedy" tones.

the A above it, the upper A is flattened till it beats exactly 4 times in a second with the lower. (This is the easiest number to count. Generally either a very exact compensating metronome has to be used, or the beats must be counted through 10 to 100 seconds, and then the number of beats divided by the number of seconds. Less than 1 and more than 6 beats in a second are difficult to count with certainty, more than 8 almost impossible.) A third fork is now tuned 4 beats (in a second, as must be always understood) sharper, and will give the exact octave of the lowest fork, without any wave or error. Then proceeding downwards by 4 beats at a time we reach a fork which beats sharp 4, or less than 4, times with the original fork, and these beats are accurately counted. The sum of all the beats of all the forks, two and two, from the lowest to the highest, is necessarily the exact number of vibrations of the lowest, because these beats represent the number of vibrations to be added to the lowest in order to produce its octave, the highest, which has twice as many vibrations. Thus, the absolute pitch is known of all the forks used, and forks can be tuned to any intermediate pitch by less than 4 beats in a second. The construction of such tonometers of forks, large in size, never touched by the hand, kept at a constant temperature, and anxiously observed and re-observed, is a matter of great difficulty. Scheibler's original tonometer had 52 forks extending from A  $219\frac{2}{3}$  (that is the note called A, and making  $219\frac{2}{3}$  vibrations in a second) to A  $439\frac{1}{3}$ , but proceeding by unequal numbers of beats. Koenig, of Paris, subsequently improved on this by making one of 65 forks from c 256, to c 512, proceeding by 4 beats, and added two other forks F  $341\frac{1}{3}$ , and A  $426\frac{2}{3}$ . This is priced in his catalogue of 1865 at 2,000 francs, or 80*l*. Scheibler's own tonometer was made in 1834, by Kämmerling (long since deceased), in Crefeld, for sixty dollars, or 9*l*., paid at time of ordering (*Tonmesser*, p. 80).

These instruments, with proper precautions, do excellent work. But they are cumbrous, costly, excessively variable with temperature, extremely mild in quality of tone, which prevents verification by any interval but the octave; with notes difficult to sound more than two at a time, and difficult to flatten and restore to pitch rapidly. These inconveniences are practically overcome by the tonometer made by Georg Appunn and Son (of Hanau, Hessen-Cassel, near Frankfort-on-the-Main), now in the Loan Collection of Scientific Apparatus at South Kensington, and priced, as I find on inquiry (it is as well to

state that I have none but a scientific interest in the apparatus) at 360 German marks, or 18*l.*, without the blowing apparatus, which adds about 6*l.* or 7*l.* more. It is of small and comparatively convenient size, and its tones are not nearly so much affected by change of temperature as those proceeding from tuning-forks. The notes are extremely reedy in quality of tone, so that the 16th partial can be made effective, and hence all intervals used as verifications. The notes are also easy to sound and to damp in any number at a time; and to flatten, any one separately and instantly or gradually, by 1, 2, or even 3 vibrations, and to restore immediately to the former pitch. This last is one of the most important properties of the instrument. It consists of 65 harmonium reeds, actuated by pulls numbered 0 and 1 to 64, which when pulled out completely give the true tone, and when gradually pushed in, gradually flatten the tone. The pitch is from *c* 256 to *c* 512, increasing regularly by 4 vibrations.

Using this instrument to measure forks, I found great discrepancies between the numbers shown and the numbers stamped on the forks. For my own satisfaction, therefore, I verified the instrument as follows. First I counted the beats with a pocket chronometer between pulls 0 and 1 for 15 seconds, and found them 60, or 4 in a second. Next I counted the beats between each pair of the other adjacent pulls for 20 seconds, and found them always 80, or 4 in a second. Hence the whole increase was 4 times 64, or 256 vibrations. I then examined, first, the usual consonances on the instrument, consisting of 1 Octave 1:2, 11 Fifths 2:3, 11 Fourths 3:4, 10 major Thirds 4:5, 9 minor Thirds 5:6, 4 major Sixths 3:5, 4 minor Sixths 5:8; secondly, the septimal consonances, 6 sub Fifths 5:7, 4 super-major Thirds 7:9, 8 sub-minor Thirds 6:7, 3 sub-minor Sevenths 4:7; and thirdly, the usual dissonances, having audible identical partials, 7 major Tones 8:9, 5 minor Tones 9:10, 4 diatonic Semitones 15:16; or 87 just intervals on the whole. For every one there was the proper rapid rattle of beating partials, but not the slightest wave of error in the identical partials. This wave was, however, instantly produced by flattening the upper reed, and made to disappear by flattening the lower reed at the same time to the proper extent, and to reappear by flattening the same more. I have, therefore, a mechanical guarantee that every one of these intervals was correctly represented on the instrument. But every one of them separately proved, after counting the beats, that the lowest tone made 256 vibrations in

a second, and the whole set by their perfect agreement proved that the beats had been correctly counted.<sup>1</sup> The introduction and extinction of the beats of error were often very remarkable. Thus the diatonic semitone, pulls 11 and 16, with 300 and 320 vibrations, when the upper note was flattened, beat in error with 4,800, and the same slightly altered; that is, a *D sharp* above the ninth leger line above the treble staff, and the same slightly altered. This slow beat of error was distinctly separable from the rapid rattle of the beating partials, including the lowest and strongest. By conscientiously trying every one of these 87 cases, I have convinced myself of the perfect trustworthiness of the instrument, and those to whom I have shown some of them, have been equally convinced, among whom I need only mention as most competent to decide, Mr. A. J. Hipkins of Messrs. Broadwoods, and Mr. E. Greaves of Sheffield, a large maker of tuning-forks for Messrs. Broadwoods, and the whole music trade, who has now accepted the 256, 384, and 512 of Appunn's instrument, as absolutely correct, and copied them on forks.

An examination, by means of this tonometer, of a number of standard forks, developed some remarkable results. [It is stated that the pitch of the Paris opera, 1699, was A 404, c 480·44, and it is quoted here as the lowest pitch on record, but the correctness of the statement is questionable.] Handel's fork, 1751, gave A 426·4, c 507·14—this fork was used at the Foundling Hospital, when the Messiah was performed, and a contemporaneous note stated, "Antient concert, whole note higher; Abbey, half tone higher; Temple and St. Paul's organs exactly with this pitch." A series of other forks from the best authorities, proved to vary in small amounts from their supposed values, and compared when reduced to Cs 510·1, 512, 515·82, 517, 517·25, 518·52, etc.; while a French normal, which should have been A 435, proved A 439, c 522·06. Close to this figure comes

<sup>1</sup> Let  $x$  be the vibrations of the lowest note,  $p$  and  $q$  the beats added by pulls  $P$  and  $Q$ , found by counting, so that the reeds actuated by  $P$  and  $Q$  gave  $x + p$  and  $x + q$  vibrations, and let  $m : n$  be the ratio of the interval. Then, by the preceding foot-note,  $n(x + p) = m(x + q)$ , or  $(n - m)x = mq - np$ , which gives the value of  $x$  in each case. Thus pulls 10 and 47 give a Fifth 2 : 3, and counting gives  $p = 4 \times 10 = 40$ ,  $q = 4 \times 47 = 188$ . Hence  $(3 - 2)x = 2 \times 188 - 3 \times 40$ , or  $x = 256$ , and so for all the 87 cases. Had there been any error in counting, it would have been detected by one or more of these cases not giving  $x = 256$ . Of course, these perfect intervals render the instrument invaluable to any teacher of musical acoustics.

the fork of Sir George Smart, c 521, Messrs. Broadwoods' "low pitch" c 523. The "Stuttgart pitch" c 523.25, the Vienna orchestra, 1834, c 524.29. [The Soc. of Arts' standard, which is theoretically c 528, but which was never made, can be compared to these last results.] And finally, there was tested a series of higher forks, Broadwoods' medium c 535, and others, of which Sir M. Costa's Philharmonic Wind Band Concerts of c 542.5, and Broadwoods' high-pitch c 545.2 are examples.

The above statements having been carefully read over to Mr. A. J. Hipkins, he concurs in the accuracy of all that relates to himself, and to the forks in possession of himself and Messrs. Broadwoods, which he obligingly brought to me for measurement. It is hoped that the above measurements, and especially Appunn's convenient tonometer, a copy of which should be in all musical centres, will contribute to settle the question of Standard Pitch in England. It will be seen that the real French normal A 439 = c 522, and Scheibler's A 440 = c 523 $\frac{1}{4}$ , and Messrs. Broadwoods' "low pitch," c 523, seem to unite the greatest number of pitches in actual use.

## CERTAIN POINTS IN THE DEVELOPMENT AND PRACTICE

OF

## MODERN AMERICAN LOCOMOTIVE ENGINEERING.

By FRANCIS E. GALLOUPE, S.B.

Continued from Vol. ciii, page 28.

*The Efficiency of the Heating Surface* is equal to the ratio of the difference of temperature of the hot gases on first coming in contact with it, and on leaving it, to the amount of heat transmitted by it to the water; or, calling  $T_1$  the temperature of the hot gas at first,  $T_2$  its final temperature, and  $t$  the temperature of the water, its efficiency,  $e = \frac{T_1 - T_2}{T_1 - t}$ .

The efficiency of the furnace is the proportion that the available heat from one pound of fuel bears to its total heat of combustion. The laws of combustion are fixed and definite, and the boiler should be so proportioned as to conform to them. With the heating surface, however, it is found that no two portions have the same efficiency. The efficiency depends upon a number of conditions, the extent of