

**CIHM
Microfiche
Series
(Monographs)**

**ICMH
Collection de
microfiches
(monographies)**



Canadian Institute for Historical Microreproductions / Institut canadien de microreproductions historiques

© 1996

Technical and Bibliographic Notes / Notes techniques et bibliographiques

The Institute has attempted to obtain the best original copy available for filming. Features of this copy which may be bibliographically unique, which may alter any of the images in the reproduction, or which may significantly change the usual method of filming, are checked below.

L'Institut a microfilmé le meilleur exemplaire qu'il lui a été possible de se procurer. Les détails de cet exemplaire qui sont peut-être uniques du point de vue bibliographique, qui peuvent modifier une image reproduite, ou qui peuvent exiger une modification dans la méthode normale de filmage sont indiqués ci-dessous.

Coloured covers/
Couverture de couleur

Coloured pages/
Pages de couleur

Covers damaged/
Couverture endommagée

Pages damaged/
Pages endommagées

Covers restored and/or laminated/
Couverture restaurée et/ou pelliculée

Pages restored and/or laminated/
Pages restaurées et/ou pelliculées

Cover title missing/
Le titre de couverture manque

Pages discoloured, stained or foxed/
Pages décolorées, tachetées ou piquées

Coloured maps/
Cartes géographiques en couleur

Pages detached/
Pages détachées

Coloured ink (i.e. other than blue or black)/
Encre de couleur (i.e. autre que bleue ou noire)

Showthrough/
Transparence

Coloured plates and/or illustrations/
Planches et/ou illustrations en couleur

Quality of print varies/
Qualité inégale de l'impression

Bound with other material/
Relié avec d'autres documents

Continuous pagination/
Pagination continue

Tight binding may cause shadows or distortion along interior margin/
La reliure serrée peut causer de l'ombre ou de la distorsion le long de la marge intérieure

Includes index(es)/
Comprend un (des) index

Title on header taken from:/
Le titre de l'en-tête provient:

Blank leaves added during restoration may appear within the text. Whenever possible, these have been omitted from filming/
Il se peut que certaines pages blanches ajoutées lors d'une restauration apparaissent dans le texte, mais, lorsque cela était possible, ces pages n'ont pas été filmées.

Title page of issue/
Page de titre de la livraison

Caption of issue/
Titre de départ de la livraison

Masthead/
Générique (périodiques) de la livraison

Additional comments:/
Commentaires supplémentaires:

Pagination is as follows: p. 43-54.

This item is filmed at the reduction ratio checked below/
Ce document est filmé au taux de réduction indiqué ci-dessous.

10x	14x	18x	22x	26x	30x
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
12x	16x	20x	24x	28x	32x

The copy filmed here has been reproduced thanks to the generosity of:

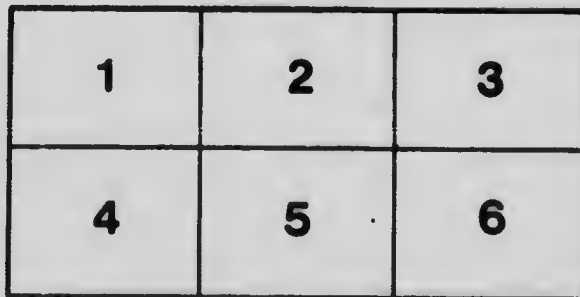
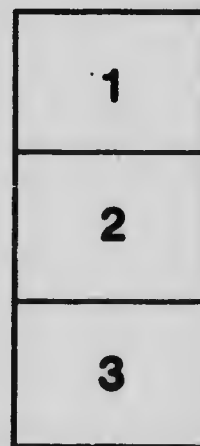
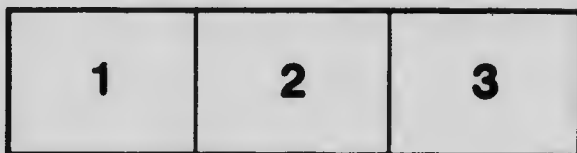
Thomas Fisher Rare Book Library,
University of Toronto Library

The images appearing here are the best quality possible considering the condition and legibility of the original copy and in keeping with the filming contract specifications.

Original copies in printed paper covers are filmed beginning with the front cover and ending on the last page with a printed or illustrated impression, or the back cover when appropriate. All other original copies are filmed beginning on the first page with a printed or illustrated impression, and ending on the last page with a printed or illustrated impression.

The last recorded frame on each microfiche shall contain the symbol \rightarrow (meaning "CONTINUED"), or the symbol ∇ (meaning "END"), whichever applies.

Maps, plates, charts, etc., may be filmed at different reduction ratios. Those too large to be entirely included in one exposure are filmed beginning in the upper left hand corner, left to right and top to bottom, as many frames as required. The following diagrams illustrate the method:



L'exemplaire filmé fut reproduit grâce à la générosité de:

Thomas Fisher Rare Book Library,
University of Toronto Library

Les images suivantes ont été reproduites avec le plus grand soin, compte tenu de la condition et de la netteté de l'exemplaire filmé, et en conformité avec les conditions du contrat de filmage.

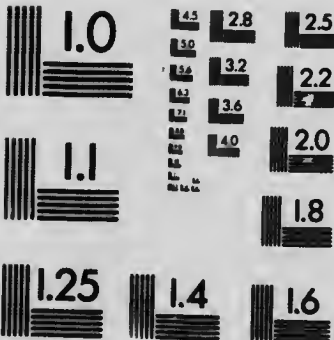
Les exemplaires originaux dont la couverture en papier est imprimée sont filmés en commençant par le premier plat et en terminant soit par la dernière page qui comporte une empreinte d'impression ou d'illustration, soit par le second plat, selon le cas. Tous les autres exemplaires originaux sont filmés en commençant par la première page qui comporte une empreinte d'impression ou d'illustration et en terminant par la dernière page qui comporte une telle empreinte.

Un des symboles suivants apparaîtra sur la dernière image de chaque microfiche, selon le cas: le symbole \rightarrow signifie "A SUIVRE", le symbole ∇ signifie "FIN".

Les cartes, planches, tableaux, etc., peuvent être filmés à des taux de réduction différents. Lorsque le document est trop grand pour être reproduit en un seul cliché, il est filmé à partir de l'angle supérieur gauche, de gauche à droite, et de haut en bas, en prenant le nombre d'images nécessaire. Les diagrammes suivants illustrent la méthode.

MICROCOPY RESOLUTION TEST CHART

(ANSI and ISO TEST CHART No. 2)



APPLIED IMAGE Inc

1653 East Main Street
Rochester, New York 14609 USA
(716) 482 - 0300 - Phone
(716) 288 - 5989 - Fax

FROM THE TRANSACTIONS OF THE ROYAL SOCIETY OF CANADA

SECOND SERIES—1901-1902

VOLUME VII

SECTION III

MATHEMATICAL, PHYSICAL AND CHEMICAL SCIENCES

A Century of Progress in Acoustics

PRESIDENTIAL ADDRESS TO SECTION

By PRESIDENT J. LOUDON, LL.D.

FOR SALE BY

J. HOPE & SONS, OTTAWA; THE COPP-CLARK CO., TORONTO
BERNARD QUARITCH, LONDON, ENGLAND

1901



VII.—*A Century of Progress in Acoustics:—Presidential Address
to Section.*

By PRESIDENT J. LOUDON, LL.D.

(Read May 23, 1901.)

In selecting the Progress of Acoustics, on its experimental side, as the subject for this year's Presidential Address, I am fully alive to the fact that this branch of science has been comparatively neglected by physicists for many years, and that consequently I cannot hope to arouse the interest which the choice of a more popular subject might command. It is, however, just because of this neglect of an important field of science that I conceive it to be my duty to direct some attention thereto. This duty I can best perform, it seems to me, by taking a survey of the work accomplished in this particular field during the century that has just closed. Such a survey will make it evident not only that the science of acoustics has made immense progress during that time, but also that many of the experimental methods in use in other branches of physical science were invented and first employed in the course of acoustical research. This latter fact, though not generally recognized, furnishes an illustration of the interdependence which exists between the various branches of physical science, and suggests the probability that the work of acoustical research in the future may be advanced by experimental methods specially assigned for investigation in other fields. A revival will, of course, come in time for acoustics, as it has recently come for electricity, and it ought to come all the sooner because of the co-operation which physicists may naturally look for from those who are cultivating the new fields of experimental psychology.

In order to avoid the tedium of a bare enumeration of discoveries arranged chronologically, I propose to refer, in the first instance, to the invention of the various experimental methods which have been employed in acoustical research. A separate reference to these methods will enable us to appreciate their potency in the advancement of this science.

The earliest of these methods is due to Chladni whose work "Die Akustik" appeared in the form of a French translation in 1809 under the title "Traité d'Acoustique de Chladni". In this work were collected all the researches on the vibrations of bodies which Chladni had conducted with the aid of the new method (méthode de sable.) This method consists in distinguishing, on the surfaces of vibrating bodies,

the parts which are vibrating from the parts which are in repose, by means of the sand which is driven from the former to collect on the latter. In these experiments of Chladni on plates, etc., the violin bow was used for the first time to produce the necessary vibrations. The bow had previously been used only for vibrating cords, the "violon de fer", and other musical instruments. Chladni made his discovery of sand figures in 1787, having been led thereto by Lichtenberg's discovery of electric figures.

The transversal nodal lines given by Chladni's method in the case of rods vibrating longitudinally were readily explained. Not so, however, the complicated nodal lines presented by vibrating plates, or the alternate lines which appear on the two sides of rods vibrating longitudinally, and which sometimes also appear on rods vibrating transversally. It was not until 1833 that an explanation of the former of these phenomena was offered by Wheatstone's theory that the nodal lines were due to the superposition of transversal vibrations, corresponding to sounds of the same pitch coexisting with respect to different directions in the plate. This theory was confirmed experimentally in 1864 by Rudolph Koenig who constructed rectangular plates giving unison notes corresponding to different sets of nodal lines parallel to two adjacent sides of the plate. The theoretical figure results when the plate is vibrated so as to produce the coexisting unison notes.

The alternate nodal lines given by vibrating rods were also explained by the theory of the coexistence of two sounds near unison in the same vibrating rod. In this case, however, one sound corresponds to longitudinal and the other to transversal vibrations. This explanation was first given by August Seebeck in 1849, whose theory was confirmed in 1859 by Terquem in a very important paper "Sur les vibrations longitudinales des verges libres aux deux extrémités."

The Graphical Method.—In 1807, five years after the publication of Chladni's "Akustik," appeared Dr. Thomas Young's "Course of Lectures on Natural Philosophy and the Mechanical Arts," in which we find the earliest description of the graphical method, including its application to chronography. This description is as follows:

"By means of this instrument we may measure, without difficulty, the frequency of the vibrations of sounding bodies, by connecting them with a point which will describe an undulated path on the roller. These vibrations may also serve in a very simple manner for the measurement of the minutest intervals of time; for if a body, of which the vibrations are of a certain degree of frequency, be caused to vibrate during the revolution of an axis, and to mark its vibrations on a roller, the traces will serve as a correct index of the time occupied by any part of a revolution, and the motion of any other body

may be very accurately compared with the number of alternations marked, in the same time, by the vibrating body". Notwithstanding the clearness of this description, the graphical method remained for a long time unknown, and when it was developed later in 1864 the original discovery was incorrectly attributed to Wilhelm Weber (1830). Between these dates slight applications of the method had been made by Savart, Duhamel, Lissajous and Desains, Wertheim and others; the most important of such applications being that of Scott, who in 1858 applied it to his Phonautograph. Finally, from 1858 to 1862, Rudolph Kœnig devoted himself specially to the perfection of this method, and exhibited the results of his labours at the Exhibition in London in 1862, in the form of a large collection of phonograms. This collection in its seven sections comprises all the applications of the method which have so far been made in acoustics. Whilst the progress of this method was thus slow before 1862, its use from that time onward became general, especially in physiological researches, in connection with which it received its widest development in the publication by M. Marey of his splendid work, "*La Méthode graphique*" in 1878. Parenthetically I might remark that Edison's Phonograph (1877) was doubtless suggested by Scott's Phonautograph.

Optical Methods.—As with the graphical methods, the earliest suggestion of an optical method of studying vibratory movements came from Dr. Thomas Young, who in 1807 described the construction of curves resulting from the composition of two rectangular vibratory movements. The practical realization of these curves was effected in 1827 by Wheatstone in his Kaleidophone. The most important advance, however, in the development of this method was made by Lissajous who, after some preliminary work in 1855, published in 1857 his great paper entitled "*Mémoire sur l'étude optique des mouvements vibratoires*". The optical effects produced by Lissajous' method, especially when the curves were projected on the screen, were so beautiful that the method obtained general recognition, and became immediately popularized. The chief merit of the method, however, does not lie in the beauty of the effects thus obtained, but rather in the fact that by this means we are enabled to determine with facility and with the utmost accuracy both the interval and the difference of phase between two vibratory movements. It is this fact which renders the Optical Comparator one of the most important instruments at the disposal of the acoustician.

A second optical method we owe to Biot who, in 1820, showed that the changes in density at the nodes of a transparent body vibrating longitudinally could be exhibited when the nodal line of the body is placed between the crossed mirrors of a polarization apparatus. During

the continuance of the vibrations the image is highly illuminated in the analyser and becomes darkened when the vibrations cease. This method was developed much further by Kundt in 1864 and by Mach in 1873.

A third optical method was devised by Tœpler and Boltzmann in 1870 for the purpose of exhibiting the changes which take place at a nodal point of a vibrating column of air. This method consists in producing interference bands by means of two rays of intermittent light from the same source, one of which passes through the air in its normal state, and the other through a nodal point of the vibrating air column. A vibratory movement of the interference bands results, a movement which can be made as slow as we please, thus rendering it possible to deduce by stroboscopic methods exact measurements as to the movement of the air at the nodal point.

Method of Manometric Flames.—The object of the method of manometric flames, invented by Rudolph Kœnig in 1862, is to furnish an ocular proof of the variations in density at a point of the air traversed by waves originating in another body or in the air itself. A short description of the first apparatus based on this method appeared in Pogendorff's "Annalen" in 1864. Between that year and 1872 the method was applied to a series of instruments, the experiments being described in the same Journal in a long memoir entitled "Les Flammes manométriques". Although this method is extremely sensitive and capable of furnishing very accurate results, it has been prevented for a long time from rendering more efficient service on account of two causes: first, the want of sufficient brightness in the reflected images of the jumping flames, and second, the difficulty of observing the details of these images owing to their momentary appearance in the mirror. The former of these difficulties has now been overcome by the employment of acetylene and other gases, which at the same time allow admirable photographs of the flames to be taken, thus obviating the second difficulty also. We owe an important paper on this subject to Professors E. L. Nichols and Ernest Merritt, published in 1898 in the "Physical Review".

Kundt's Method.—In 1865 Kundt published his method of using light powders for the purpose of exhibiting the vibratory character of stationary air waves in columns and plates of air. During the existence of these vibrations the light powders arrange themselves in transversal striæ which collect around the loops, and are wanting at the nodes. As in the case of the nodal lines on Chladni's plates, a satisfactory explanation of these striæ was for a long time wanting. In 1890 Professor Walter Kœnig showed from hydrodynamical considera-

tions, that the particles of the powder necessarily arrange themselves in planes at right angles to the direction of the vibratory movements, and that their observed distribution at the loops and nodes is in accordance with the same laws.

Method of Slow Movements.—Before the invention of the preceding methods the acoustician occasionally resorted to the device of deducing the vibrations of a sounding body from the behaviour of a similar body whose movements were of sufficient amplitude to be seen by the eye, and so slow that they could be readily counted. In this way Mersenne counted the vibrations of a cord 15 feet long under a stretching force of 7 pounds, and found them to be 10 per second. In shortening the cord to 1-20 of its length, he obtained an audible sound whose pitch he concluded corresponded to 10 vibrations per second. In the same way Chladni employed a long thin metal rod, which gave in the first instance only 4 vibrations per second. He then shortened the rod until it gave an audible sound, whose pitch he determined from the law expressing the relation between the length and the number of vibrations. This method, however, which appears so simple in theory is subject to large errors and gives in practice very poor results.

The Stroboscopic Method.—Mersenne's and Chladni's method has accordingly given place to another—the stroboscopic—which allows the vibrations of the sounding body to be viewed directly, its movements relatively to a vibrating eye-piece being rendered as slow as we please. The first use of stroboscopic discs for the purpose of observing very rapid periodic movements was made by Plateau in 1836. His discovery, however, remained unnoticed, for Doppler in 1845 published a note on the same subject, without referring to Plateau's discovery. It was Töpler who first made the method generally known by employing it in a series of acoustical experiments, which he published in Poggendorff's "Annalen," volume 128. In the earlier applications of this method, the view of the vibrating body was rendered intermittent by looking through slits which were opened and closed in rapid succession. This plan was modified by Mach who caused the vibrating body to be illuminated by intermittent light.

If now we allow the stroboscopic images of a moving body to fall on a photographic plate, giving the plate a movement of translation which is arrested before each appearance of the image, we thereby obtain a series of photographs of the successive positions assumed by the body. If, further, matters are so arranged that the beginning and duration of the phenomenon are traced on the images, we have a new method, which is called Chronophotography. It was M. Janssen who first conceived the idea of taking automatically a series of photo-

graphic images in order to determine the successive positions at different times of the planet Venus in its passage across the sun. It was Janssen also who, in 1876, first suggested the idea of applying successive photograms to the study of animal locomotion. The analysing of such movements was first accomplished by Muybridge of San Francisco. The method has been largely extended and perfected by M. Marey, who has employed it in studying the locomotion of all sorts of subjects, from men to insects.

Electric Transmission.—The electric transmission of sound was first accomplished by Philipp Reis in 1861. The discovery, however, not having been properly announced to the scientific world, did not receive the attention it deserved. Had it been published by Poggendorff, to whom it is said a preliminary note on the subject was sent, Graham Bell's invention of the telephone (1876) would probably have been reached at an earlier date.

The Wave-Siren Method.—The last of the methods to be noticed is that employed by Rudolph Kœnig in his Wave-siren. In this instrument a metal band or disc with curvilinear edges passes before a narrow slit from which issues a current of compressed air. By means of these discs we can produce either simple sounds, or sounds of various timbres, containing such harmonics as we please, the intensities and phases of the latter being varied at will. The first wave-siren was constructed in 1867, and the account of the first series of experiments was published in 1881.

The mere enumeration of the methods of acoustical research which have been devised since the days of Chladni is an indication of the enormous advances which have been made in this branch of science. It remains now to state more particularly what these additions to our knowledge of acoustical phenomena have been. This can be most conveniently done under the following heads, viz:—the velocity and diffraction of sound; its pitch, intensity and timbre; and the phenomena produced by the coexistence of two or more sounds.

The Velocity of Sound.—Long before the beginning of the last century it had been observed that the propagation of sound was not instantaneous. Mersenne in fact had tried to estimate the velocity by experiments on echoes, and by counting the time which elapses between the flash of a gun and the report. The latter experiments were also repeated by Kircher as well as by the Academy of Florence in 1660. The same experiments were subsequently, in 1738, undertaken by members of the Academy of Sciences at Paris; by savants, such as Kœstner, Benzenberg, Goldingham, and by others; but the results obtained did not gain the confidence of the scientific world. A new series of experiments was accordingly undertaken in 1822, on the sug-

gestion of Laplace, by members of the Bureau des Longitudes, to determine the velocity in air and other media. These experiments, which were the beginning of truly scientific work in this subject, were performed by Prony, Arago, Mathieu, A. de Humboldt, Gay-Lussac and Bouvard, between Montlhéry and Villejuif, cannon being fired at both stations. The result obtained was 331 m. at zero temperature, with an increase of 0.6 m. for each degree above zero. In the course of these experiments it was observed that the cannon fired at Villejuif were all distinctly heard at Montlhéry, whilst the reciprocal reports were so faint that only a small number were heard. Tyndall long afterwards, in 1875, explained this curious phenomenon, attributing it to the existence at Villejuif of a heterogeneous atmosphere, caused by the heated air which came from Paris.

Since the memorable experiments of the Bureau des Longitudes of Paris, various individuals have from time to time undertaken to solve the same problem. Among these may be mentioned Moll and van Beck (at Utrecht), Gregory Woolwich, Stone and Captain Perry in voyages to the polar regions in 1822, 1824, and Kendall in the Franklin expedition in 1825. In some of these experiments the temperatures ranged from 2° to -40° , the results obtained according with the theoretical values. In 1823 Stampfer and Myrback conducted experiments between two stations in the Tyrol at a difference of level of 1364 m.; a similar experiment being undertaken in 1844 in Switzerland by Bravais and Martin with a difference of level of 2079 m. Both experiments confirmed the law that the velocity of sound in air is independent of the pressure.

In all these experiments the exactness of the results was affected by the difficulty of estimating accurately the time between the perception of the flash and that of the report. Different observers of course gave different estimates. This source of error was first eliminated by Victor Regnault, who in his long series of researches between 1860 and 1870 made use of the graphical method, electric signals being employed to measure time intervals. Regnault's experiments were conducted in 7 tubes (part of the Paris sewers) varying in length from 70 m. to 4900 m., and of diameters from 0.11 m. to 1.10 m. Experiments were also conducted in the open air by means of reciprocal shots fired from two stations at a distance of 2445 metres. The number of the shots fired was 334. These researches of Regnault represent such an enormous amount of work that I shall attempt to give only the principal conclusions deducible from them:

1. In a cylindrical tube the intensity of the wave varies, diminishing with the distance. The narrower the tube, the more rapid is the diminution.

2. The velocity of the sound decreases as the intensity diminishes.
3. The velocity approaches a limiting value, which is higher, the greater the diameter of the tube. The mean value in dry air at 0° in a tube of diameter 1.00 m. is 330.6 m.
4. The velocity is not affected by the mode of producing the sound wave.
5. The velocity in a gas is independent of the pressure.
6. The ratio of the velocities in air and any other gas is $\sqrt{\frac{1}{\delta}}$, where δ is the density of the gas, supposed perfect.
7. The average of the results of all the experiments in the open air is $v=330.7$ m. at 0° .

Regnault was also the first to attempt direct experiments for determining the velocity of musical sounds. In this case, however, the electric signals and the graphical recording apparatus were not sensitive enough to respond to the front of the wave, and it became necessary to resort to the ear alone. In these experiments Regnault had the co-operation of Koenig as observer, with whose assistance it was shown that :

1. A note does not change sensibly when it traverses long distances in tubes of large diameter.
2. When the sounds are observed by the ear the velocity of high notes appears to be less than that of low ones. This may be due to the more ready response which the tympanum makes in the case of low notes.
3. In reversing tubes of great length, a note does not preserve its timbre, being resolved into its simple components.

Regnault's experiments have recently been repeated by M. Violle in the large sewers near Grenoble and Argenteuil, some of Regnault's apparatus being employed for the purpose. The results of these experiments have not, however, been yet published.

Diffraction.—The phenomenon of the diffraction of sound was first experimentally shown by Lord Rayleigh in 1880.

Pitch.—Before the last century, as already mentioned, Mersenne had attempted to determine the vibrations of a cord by deducing them from very slow vibrations of the same cord when lengthened. Chladni's tonometer, which consisted of a vibrating metal rod of variable length, was based on the same principle. In 1819 Cagniard de la Tour invented the siren, a much superior instrument, but incapable of giving very exact results, notwithstanding the simplicity of its mechanism. The same remark may be made of the toothed wheel invented by Savart in 1830.

A most important step in advance was made in 1834 by Henri Scheibler of Crefeld, who in that year invented his tonometer, consisting of a series of 56 forks going from A (440) to its octave (880), the vibrations increasing regularly by differences of eight, any two adjacent forks thus giving four beats per second. Curiously enough, although Scheibler went to Paris and exhibited his tonometer there, he was unable to interest savants in his discovery; and it was not until the London Exhibition of 1862 that the attention of physicists and musicians was directed to the value of the instrument by Kœnig. The apparatus in its new form contained 65 forks going from $C = 512$ to $C = 1024$.

Notwithstanding the great utility of this tonometer to the acoustician, it still left undetermined the absolute pitch of the fundamental note, and hence of the whole series. This problem of realizing a standard of pitch remained practically unsolved even after the French Government in 1859 decreed that the standard should be $A = 870$ v.s. at $15^\circ C$. The standard then constructed by Lissajous was found, in 1880, to be too high by 9-10 of a vibration. The acoustical standard employed since 1880 by Kœnig is $C = 512$ v.s. at 20° . The acoustical standard before that date was in reality 512.35 at 20° . The problem of realizing a standard fork, which had given rise to much controversy among physicists, was finally solved in 1880 by Kœnig, who in that year published his paper "Recherches sur les vibrations d'un diapason normal." In this paper Kœnig describes how by means of a clock-fork (horloge à diapason comparateur) he established a standard fork, the error of which did not exceed 1-6000 of a vibration. The clock-fork method enables us at the same time to determine readily the variations in the number of vibrations due to a rise or fall of temperature. Having established in this way an absolute standard of 512 v.s. at $20^\circ C$., Kœnig commenced the construction of a universal tonometer based thereon, a colossal undertaking which he finished in 1897, after working on it for nearly a score of years. This tonometer consists of the following:

1. Four forks giving vibrations from 32 to 128, with differences at first of $\frac{1}{2}$ v.s., and afterwards of 1 v.s.

2. One hundred and thirty-two large forks, tuned to give (without the sliders) the 127 harmonics of $c_1 = 64$ v.s., c_2, c_3, c_4, c_5, c_6 , being in duplicate. Each fork can be lowered, by means of sliders, to unison with the fork next below. The differences immediately obtainable by sliders are:—1 v.d. between c_1 and c_3 ; 2 v.d. between c_2 and c_3 ; 4 v.d. between c_3 and c_7 .

3. 40 resonators to reinforce forks of (2).

4. One large resonator of diameter 0.48 m and of length varying from 0.30 m to 2.30 m.

5. Eighteen forks for notes from c_7 to $f_9 = 43,390.6$ v.s.

6. Fifteen forks for notes from g_9 to 180,000 v.s.

Under the head of pitch come two very difficult questions relating to the audibility of very low or very high sounds. With regard to the former, Helmholtz has shown that, if the vibrations are very slow, and do not follow the pendular law, (the fundamental being thus accompanied by a series of harmonics) the fundamental may be quite inaudible, whilst the harmonic is heard distinctly. In such a case the harmonic is often mistaken for the fundamental. On the other hand, if we employ large tuning-forks, vibrating rods, or the wave-siren for the purpose of obtaining pendular vibrations, we are still met with the difficulty of determining accurately the limit of audibility, owing to the fact that it not only depends on the intensity of the vibrations, but varies from one observer to another. In general it may be stated that it requires from 60 to 80 v.s. to produce a sound perfectly continuous and possessing a musical character. In using very powerful high forks to produce beats, which were gradually diminished in number, Kœnig found that the sensation of a continuous low sound ceased when their number did not exceed 26.

As to the high notes above $C_7 = 8192$, the amplitudes of the vibrations are generally so small, that the ordinary methods no longer serve to determine the pitch. For this reason it was at first the practice to tune forks above C_7 by means of the ear. The high forks constructed by Marloye and presented in 1848 by Depretz to the Academy of Sciences at Paris were constructed in this way. In 1858, however, Kœnig showed that even in the upper half of the octave c_6-c_7 , the best musicians ceased to judge the intervals accurately, a fact which seemed to show that it was extremely unlikely that forks giving notes two octaves higher could be tuned accurately by the ear. For this reason Kœnig effected the tuning of very high forks by means of the sounds resulting from their beats. The first series of forks tuned in this way were made by Kœnig in 1876. A set of similar forks constructed about the same time by Preyer, and going, as he alleged, as high as c_{10} , were shown by Melde in 1894 to be greatly out of tune, the intervals being wrong by as much as a third, and even an octave. In 1897 Melde's results were confirmed by Stumpf and Meyer.

In 1899 Kœnig published his researches on very high notes. In this memoir, after showing the exactness of the tuning attained by the sounds of beats in forks between c_7 and f_9 , he proceeds to state that, by means of Kundt's method of using light powders, he had con-

structed a series of high forks accurately tuned and proceeding according to the intervals of the perfect (major) scale, from c_7 to the enormous pitch of 180,000 v.s., and that without reaching a limit to the number of such vibrations.

As to the audibility of these high forks, it has been remarked by Kœnig that those between c_7 and c_9 are generally audible, whilst c_{10} and those above are entirely inaudible. He further remarks that the limit of audibility, which thus lies between c_9 and c_{10} , largely depends, as in the case of low sounds, on the intensity, and varies with the individual.

Intensity.—With regard to the question of intensity of sound, it is only necessary to say that there exists here a great lacuna in our acoustical knowledge, as we do not yet possess a means of measuring the physiological intensity of sound.

Timbre.—To Helmholtz belongs the credit of first elucidating the question of timbre by showing that the timbre of a sound depends upon the number and intensity of the harmonics which accompany the fundamental. The question of timbre is thus intimately connected with the study of the phenomena produced by the coexistence of two or more sounds. With regard to such phenomena it was stated by Helmholtz that when two notes of different pitch are sounded together, they give rise to two other sounds, the pitch of which is measured the one by the difference, and the other by the sum of the vibrations of the two primary sounds. Further, that these resultant sounds are not due to beats.

These propositions of Helmholtz are controverted by Kœnig, who, on the contrary, has proved that the sounds actually heard accompanying two primary sounds are always due to beats. Kœnig asserts, moreover, that the sounds referred to by Helmholtz, even if we could prove that they had a real existence, would always be inaudible, and therefore without effect on the acoustical phenomena. He further establishes the curious fact that even interruptions of a sound give rise to another sound.

As to timbre, Helmholtz's theory was that it depended solely on the number and relative intensities of the harmonics which accompany the fundamental, and that it is not affected in any degree by differences in the phases of these components. This latter proposition is combated by Kœnig, who holds that differences of phase as regards harmonics exercise a very important influence on the timbre of a sound, so that according to him timbre depends on the number, relative intensities and differences of phase of the harmonics which accompany the fundamental. Kœnig's experiments on this disputed point were performed

with his large wave-siren. Even this wider definition of timbre is, however, according to Kœnig's most recent view and experiments, insufficient, as not being applicable to certain classes of timbres—for example, those produced by most musical instruments, especially stringed instruments. In these cases the fundamental is accompanied not only by harmonics, but also by other sounds which are not harmonic, the superposition of which produces series of waves which change their form successively. These wave forms have been investigated by Kœnig in a paper "Sur les timbres à ondes de formes variables," in which he determines the conditions under which such timbres may be considered musical, and concludes that in these cases the fundamental is accompanied by harmonics which continually change their relative intensities and their phase-differences.

In conclusion, I may state that, according to Kœnig, the fact that differences of phase amongst harmonics produce differences of timbre is explained for the first time by his recent discovery that the intensity of a sound can be increased by the addition of another sound when the maxima of intensity in the vibrations in the two cases correspond more or less exactly, and that several sounds produced together may reinforce a sound of lower pitch than any of them. For example, with the same six primary sounds, by changing their phases only, he produces not only timbres differing in intensity and in richness, but timbres in which, at one time, the octave (2) and at another time the fifth above (3) is heard. The difference between these two timbres is, indeed, so great that when heard in succession, there appears to be an interval of a fifth between them, although their fundamentals are exactly the same. These experiments may be said to be the last on this difficult subject in the years of the century which has just closed.

